Supreme Court, U.S.
FILED
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No. 84 — 84-562

IN THE
Supreme Court of the United States

OCTOBER TERM, 1984

NICOLET INSTRUMENT CORPORATION,
a Wisconsin corporation,
Petitioner,

v.

BIO-RAD LABORATORIES, INC.
a Delaware corporation,
Respondent.

Appendix to the Petition for a Writ of Certiorari to the United States Court of Appeals for the Federal Circuit

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September 1984

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EDITOR'S NOTE

PAGES A-1 thru A-14 WERE POOR HARD COPY AT THE TIME OF FILMING. IF AND WHEN A BETTER COPY CAN BE OBTAINED, A NEW FICHE WILL BE ISSUED.

[redacted]

3319515

THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

[redacted]

Whereas, THERE HAS BEEN PRESENTED TO THE

Commissioner of Patents

A PETITION PRAYING FOR THE GRANT OF LETTERS PATENT FOR AN ALLEGED NEW AND USEFUL INVENTION THE TITLE AND DESCRIPTION OF WHICH ARE CONTAINED IN THE SPECIFICATION OF WHICH A COPY IS HEREUNTO ANNEXED AND MADE A PART HEREOF, AND THE VARIOUS REQUIREMENTS OF LAW IN SUCH CASES MADE AND PROVIDED HAVE BEEN COMPLIED WITH, AND THE TITLE THERETO IS, FROM THE RECORDS OF THE PATENT OFFICE IN THE CLAIMANT (S) INDICATED IN THE SAID COPY, AND WHEREAS, UPON DUE EXAMINATION MADE, THE SAID CLAIMANT (S) IS (ARE) ADJUDGED TO BE ENTITLED TO A PATENT UNDER THE LAW.

NOW, THEREFORE, THESE **Letters Patent** ARE TO GRANT UNTO THE SAID CLAIMANT (S) AND THE SUCCESSORS, HEIRS OR ASSIGNS OF THE SAID CLAIMANT (S) FOR THE TERM OF SEVENTEEN YEARS FROM THE DATE OF THIS GRANT, SUBJECT TO THE PAYMENT OF ISSUE FEES AS PROVIDED BY LAW, THE RIGHT TO EXCLUDE OTHERS FROM MAKING, USING OR SELLING THE SAID INVENTION THROUGHOUT THE UNITED STATES.

In testimony whereof I have hereunto set my hand and caused the seal of the Patent Office to be affixed at the City of Washington this sixteenth day of May, in the year of our Lord one thousand nine hundred and sixty-seven, and of the Independence of the United States of America the one hundred and ninety-first.

Attest:

[redacted]

Witnessing Officer.

Edward J. Brenner

Commissioner of Patents.

FORM PO 277A

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,319,515 May 16, 1967

Philip A. Flournoy

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 30, for "by refrin-" read -- birefrin- --; column 5, line 58, after "30" insert -- movement --; column 10, line 71, the equation should appear as shown below instead of as in the patent:

$$n \cos \theta_1 = \sqrt{n^2 - \sin^2\theta}$$

column 11, line 69, for "through" read -- throughout --; column 12, line 66, for "interence" read -- interference --.

Signed and sealed this 9th day of January 1968.

Attest:

Attesting Officer.

EDWARD J. BRENNER
Commissioner of Patents

May 16, 1967 P. A. FLOURNOY 3,319,515

INTERFEROMETHIC OPTICAL PHASE DISCRIMINATION APPARATUS

Filed Aug. 27, 1963 5 Sheets-Sheet 1

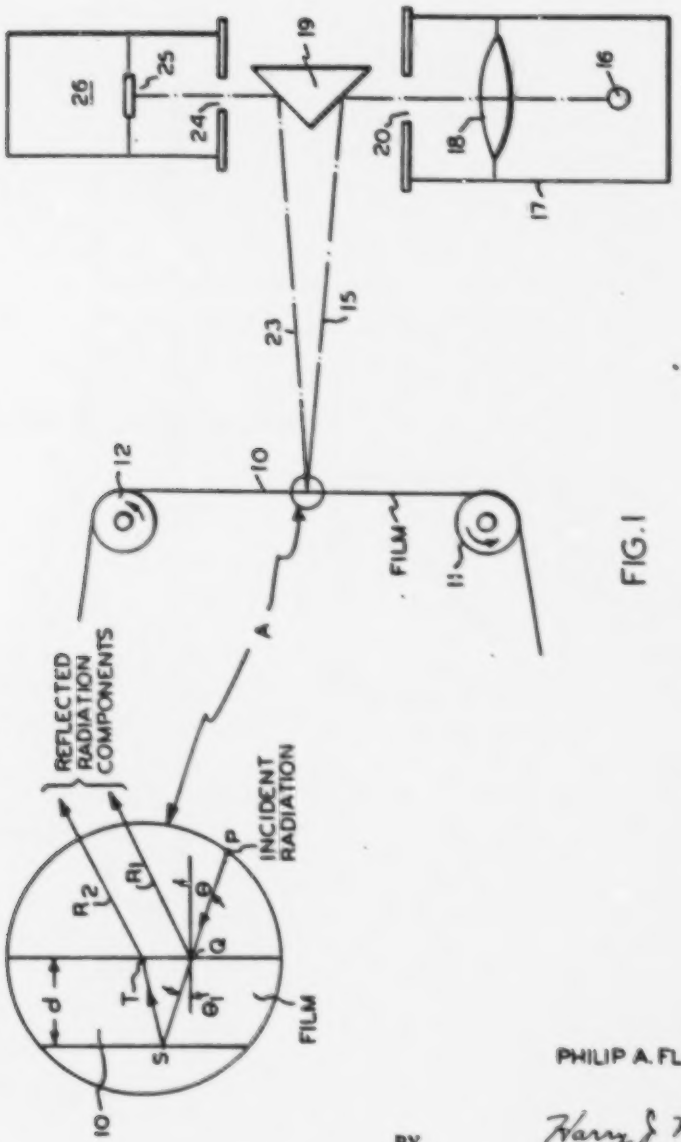

FIG. 1

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May 16, 1967 P. A. FLOURNOY 3,319,515

INTERFEROMETRIC OPTICAL PHASE DISCRIMINATION APPARATUS

Filed Aug. 27, 1963 5 Sheets-Sheet 2

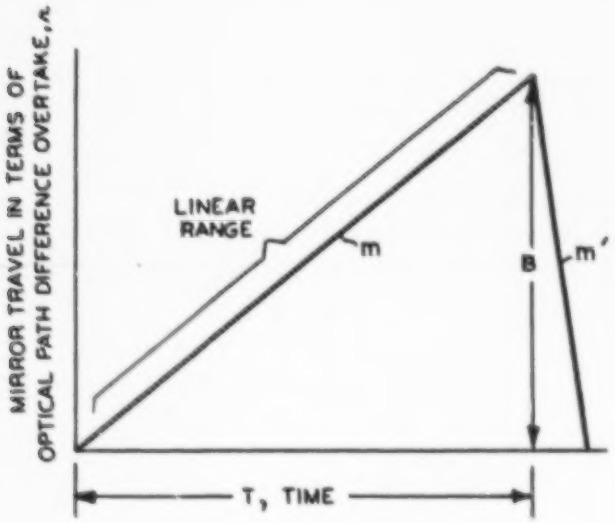

FIG.4

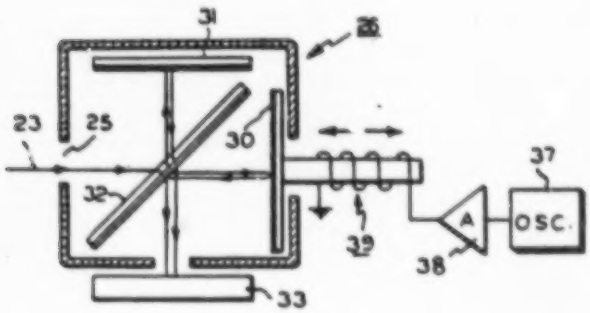

FIG.2

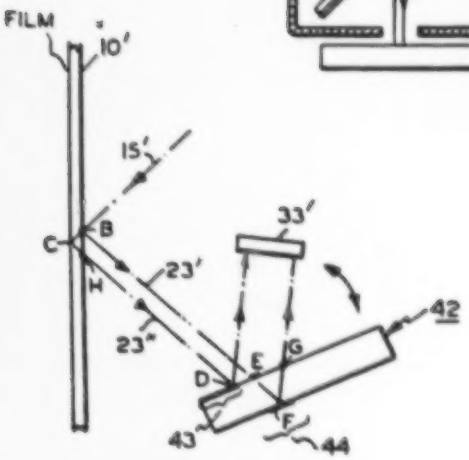

FIG.5

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May 16, 1967 P. A. FLOURNOY 3,319,515

INTERFEROMETRIC OPTICAL PHASE DISCRIMINATION APPARATUS

Filed Aug. 27, 1963 5 Sheets-Sheet 1

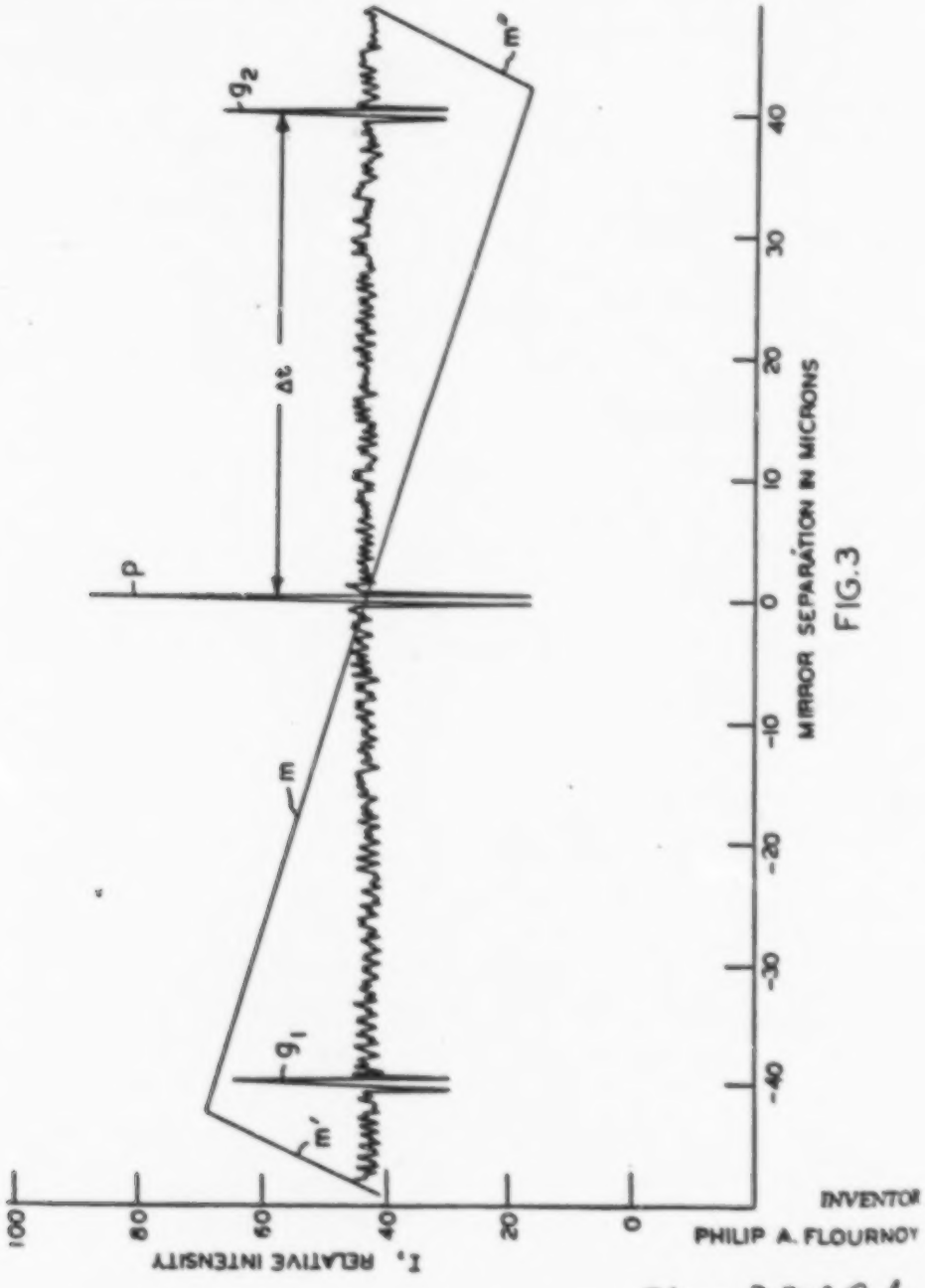

FIG. 3

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May 16, 1967 P. A. FLOURNOY 3,319,515

INTERFEROMETRIC OPTICAL PHASE DISCRIMINATION APPARATUS

Filed Aug. 27, 1963 5 Sheets-Sheet 4

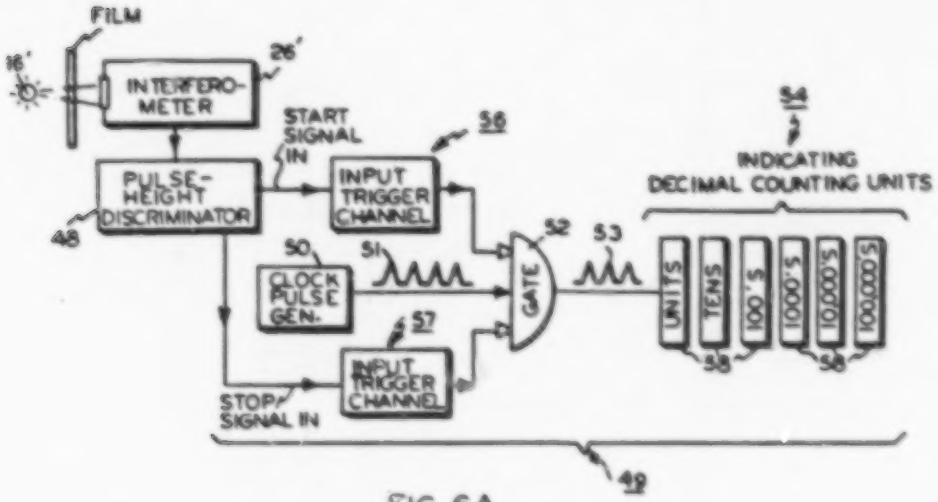

FIG. 6A

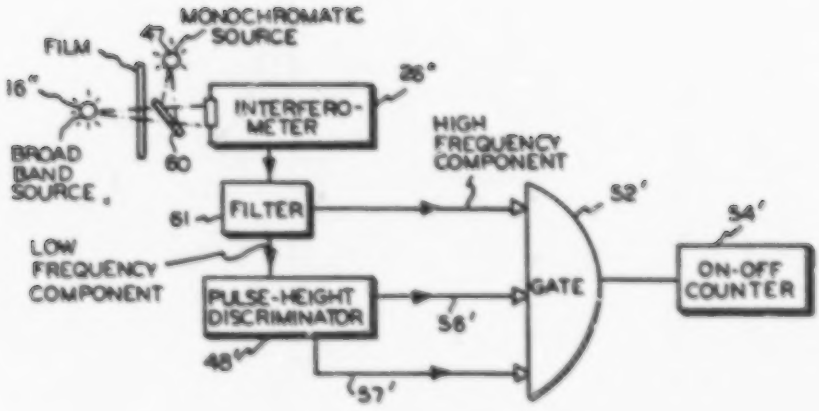

FIG. 6B

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INTERFEROMETRIC OPTICAL PHASE DISCRIMINATION APPARATUS

Filed Aug. 27, 1963 5 Sheets-Sheet 5

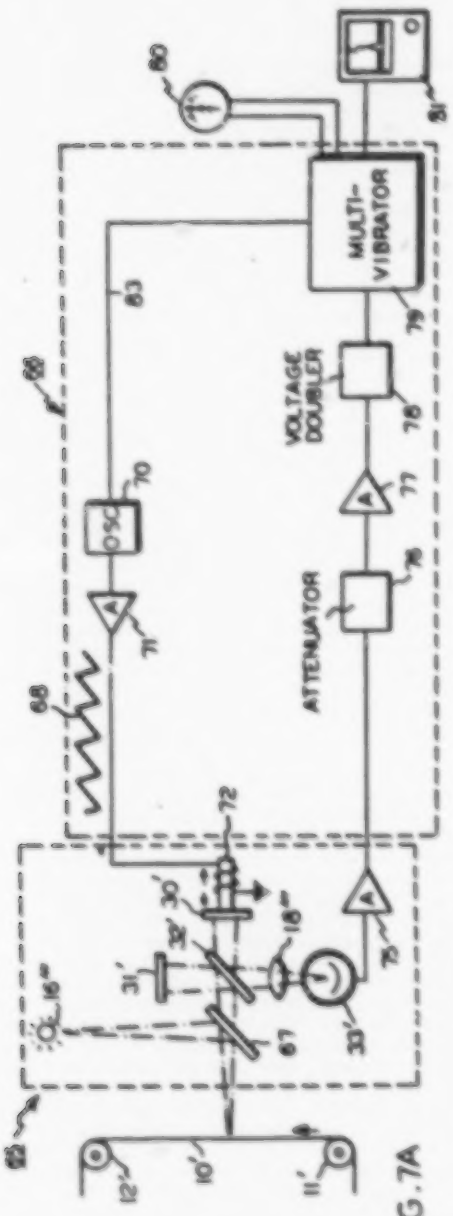

FIG. 7A

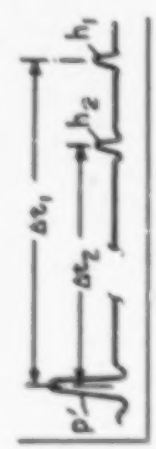

FIG. 9

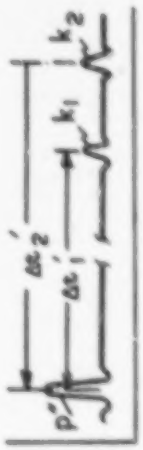

FIG. 10

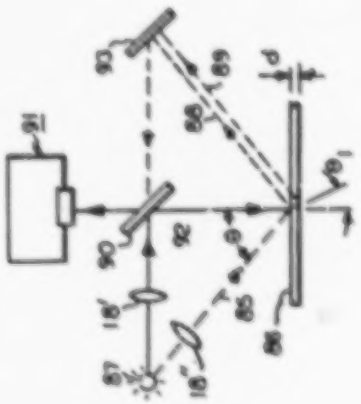

FIG. 8

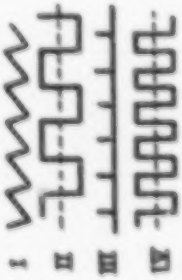

FIG. 7B

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United States Patent Office 3,319,515 Patented May 16, 1967

3,319,515 INTERFEROMETRIC OPTICAL PHASE DISCRIMINATION APPARATUS

Philip A. Flournoy, Wilmington, Del., assignor to E. I. du Pont de Nemours and Company, Wilmington, Del., a corporation of Delaware

Filed Aug. 27, 1963, Ser. No. 304,849
7 Claims. (Cl. 88—14)

This invention relates to interferometric examination, and particularly to a method and apparatus for the determination of a physical property of a specimen on the basis of interferometric optical phase discrimination.

A number of physical properties of light-reflective and transmissive substances can be measured by radiation interferometric procedures; however, the methods and apparatus heretofore evolved have been cumbersome in use and require skilled human manipulation for accuracy in the results obtained, so that they have not come into very widespread use. Thus, optical thickness gages of the type disclosed in U.S. Patents 2,518,647, 2,578,859 and 2,655,074 have a restricted application in the leisurely measurement of film thickness by trained personnel conducted on a limited number of samples, such as might be processed in a control laboratory or the like, but that is about the practical limit of their utlity.

There is a clear need for accurate, wide range, rugged, plant-type apparatus for high-speed thickness gaging of running film in the course of its modern manufacture, as there is also for apparatus adapted to measure by refringence, density, refractive index, the uniformity of application of exceedingly thin surface coatings on films such as cellophane and similar materials, or other physical properties, and this invention constitutes an improvement in this art. Other objects include the provision of a highly accurate, compact, relatively simple method and apparatus for interferometric specimen examination which is readily automated and which can be used for a wide variety of material examinations as an aid in the better understanding and control of process operations.

The manner in which these and other objects of this invention are attained will become clear from a study of the detailed film examination description which follows, taken together with the following drawings, in which:

FIG. 1 is a schematic representation of a preferred arrangement of optical equipment utilized in the gaging of a running film, the site of radiation impingement on the film being shown as an enlarged inset view, A, drawn at the bottom of the page,

FIG. 2 is a schematic representation of a reciprocatory reflector type Michelson interferometer which can be used for the development of interference indicia employed in measurement of film gage according to this invention,

FIG. 3 is an interferogram representative of the distinctive interference fringe traces obtained on either side of the central zero-order peak p obtained for the condition of equal-length interferometric arms in the apparatus of FIGS. 1 and 2, the translational time-space course of reciprocatory mirror movement being superposed to indicate its relationship to the radiation interference indicia developed in one type of operational scan of the apparatus,

FIG. 4 is a schematic representation of the time-mirror travel relationship in terms of optical path difference overtake r, for the reciprocatory mirror of the interferometic apparatus of FIG. 2,

FIG. 5 is a schematic representation of a second design of optical apparatus for the practice of this invention,

FIGS. 6A and 6B are schematic representations of two different embodiments of apparatus according to this invention operating in the radiation-transmissive mode and utilizing on-off pulse counters for time interval measurement,

FIG. 7A is a schematic representation of an embodiment of apparatus according to this invention adapted to measure variation from nominal gage of a running film,

FIG. 7B is a schematic representation of the four electrical signal wave forms employed in the apparatus of FIG. 7A,

FIG. 8 is a schematic representation of a preferred embodiment of optical apparatus for the determination of refractive index,

FIG. 9 is a diagrammatic interferogram representative of the interference fringe traces obtained in a single interferometer scan of the apparatus of FIG. 8, and

FIG. 10 is a diagrammatic interferogram representative of the interference fringe traces relied upon for measurement of birefringence according to this invention.

Generally, this invention comprises a method for determining a physical property of a specimen on the basis of interferometric optical phase discrimination comprising, in sequence, viewing the specimen with analytical radiation along a course such that there is developed an optical phase difference between radiation emanating from a first radiation-reflective surface of the specimen and from a second radiation-reflective surface of the specimen, cyclically varying at a predetermined time rate the length of the path of travel of the radiation emanating from a given one of the pair consisting of the first radiation-reflective surface of the specimen and the second radiation-reflective surface of the specimen with respect to the length of the path of travel of the radiation emanating from the other of the pair over a span inclusive of a zero-order peak at which there exists constructive interference between the radiation emanating from the first radiation-reflective surface of the specimen and from the second radiation-reflective surface of the specimen, measuring the elapsed time existing between the scan traverse of the zero-order peak at which there exists said constructive interference and a preselected reference point synchronized in time with the cycle of scan traverse, and determining the physical property of the specimen as a function of the elapsed time, together with apparatus for carrying out the method.

Referring to FIG. 1, a preferred embodiment of this invention employed in film thickness gaging can operate in the open on reflected radiation, making it possible to mount the entire apparatus on a single side of the film in process, although operation in the transmissive mode is entirely feasible, as hereinafter described with respect to FIGS. 6A and 6B particularly. Thus, the film, denoted at **10**, trained over guide rolls **11** and **12**, can be viewed with a small beam of analytical radiation **15** in the course of its running travel over the guide rolls, an upward direction of film travel being arbitrarily shown in this view. Typically, the film speed is about 120 yards/min., and, for a clear cellophane film in the range of 0.1 to 15 mils thickness, for example, the analytical radiation can be a beam of light in the near-infrared region, i.e., in the 1–3 micron range. Interferences in gage measurement occasioned by film whipping are effectively eliminated by viewing the film with the analytical radiation input at near-normal incidence.

The radiation source **16** can typically be a 35 w. tungsten-filament incandescent lamp operating from a 6 v. D.-C. power supply, not shown. Source **16** is mounted within a light-tight housing **17** provided with a double-convex glass focusing lens **18** in line with an aperture **20**, so that a 1:1 image of the hot filament of light source **16**, measuring about ¼" x ⅛" in size, is projected on the film plane via radiation-directing silvered prism **19**.

As shown in enlarged section in inset A, incident radiation **15** impinges on the front radiation-reflective sur-

face of film **10**, from whence a portion is reflected along a course R_1, whereas the bulk of the remainder is transmitted through the film, being characteristically refracted during the transit as shown. This transmitted radiation in due course encounters the back radiation-reflective surface of film **10** and part is returned towards the front surface, again with the characteristic refraction, finally leaving along a course R_2. The exit radiation from the sample, inclusive of that traveling both of the paths R_1 and R_2, is denoted collectively at **23**, which is conveniently returned to the other face of prism **19** and reflected therefrom through aperture **24** into the input port **25** of an interferometer, indicated generally at **26**.

For purposes of description, the specific interferometer used in this embodiment of the invention can be of the Michelson type shown schematically in FIG. 2, except that one radiation-reflective mirror thereof, in this instance arbitrarily chosen as mirror **30**, is reciprocated cyclically through a span hereinafter detailed, whereas the other radiation reflective mirror **31**, is maintained fixed in position. As is conventional, the interferometer embodies an inclined radiation reflecting-transmitting beam splitter **32** (typically, a ¼" thick semireflective glass plate partially mirrored on the underside, disposed at an angle of 45° with respect to mirrors **30** and **31**) which delivers the input radiation in approximately equal-intensity portions to each of the mirrors **30** and **31** from whence the beams are reflected back to beam splitter **32** as indicated by the arrow heads, being then directed outwardly in close adjacency and made to impinge on a photoelectric detector **33**, which in this case can be of the lead sulphide type. The design of interferometer described is the subject matter of copending U.S. Application Ser. No. 120,600, now Patent No. 3,266,582, and comprises a saw-tooth oscillator **37** and associated electronic power amplifier **38**, delivering cyclic saw-tooth voltage pulses to a solenoid-type electrodynamic motor indicated generally at **39**, to thereby reciprocate mirror **30** at a frequency of, typically, 50 cycles/sec.

In operation, the general principles of interferometry are utilized as follows. The phase difference a, which exists as regards any two radiation beams of wavelength λ in reaching a point of observation, such as detector **33**, is a function of the optical path difference b, and can be expressed by the equation

$$a=2\pi b/\lambda \qquad (1)$$

Where the two beams are in phase, there exists "constructive interference," which is evidenced by the development of localized high-intensity radiation regions or "fringes," whereas, where the two beams are out of phase, there is "destructive interference," or regions where the two beams cancel one another to an extent depending precisely on how far out of phase the radiation is.

Referring to inset A, FIG. 1, if the input radiation, PQ, impinges on the film at an angle θ measured from the normal, the first-reflected ray, R_1, upon which my film gage measurement is based leaves the front radiation-reflective surface of the film, whereas the remaining radiation enters the film (of thickness d) on a refracted course along angle θ_1 to point S, located on the rear surface of film **10**. A portion of this radiation is reflected back to point T on the front surface of the film along the refracted course ST, the second reflected ray upon which my measurement is based then emerging as R_2. If the film has a refractive index n, the optical path difference b between R_1 and R_2 can be calculated as

$b=2nd\cos\theta_1$ (refer, p. 262, "Fundamentals of Optics" by Jenkins and White), from which the optical phase difference, using Equation 1, specifically applied, becomes

$$a=\frac{2\pi}{\lambda}(2nd\cos\theta_1) \qquad (2)$$

The intensities of illumination reflected as beams R_1 and R_2 are, respectively, $I_1=\cos^2\theta$ and $I_2=\cos^2\theta_1$, and the intensity I of the two beams considered as a totality is, from pp. 211–213, reference supra,

$$I=4I_1\cos^2 a/2 \qquad (3)$$

Referring to FIG. 2, beam **23**, made up of R_1 and R_2 together, is split into components which are reflected on the one hand to fixed mirror **31**, and rereflected therefrom, and on the other hand to reciprocatory mirror **30**, and rereflected therefrom, giving four separate wave trains within the interferometer.

In accordance with the principles of interferometry, when the path lengths from source to mirrors are equal, there is constructive interference for all wavelengths between the emergent reflected light from the mirrors. The points at which this condition exists are called zero-order peaks, and the central one of these is where the distance of mirror **30** from beam splitter **32** exactly equals the distance of mirror **31** from beam splitter **32** or, stated another way, where the arms of the interferometer are equal. At this central zero-order peak, point Q (Inset A, FIG. 1) on the front surface of the film is effectively the common source for the two split portions of beam R_1, which then constructively interfere one with the other, whereas point S, via point T, is another distinct common source for the two split portions of beam R_2, which then constructively interfere with one another to superadd their effect to the R_1 interference. The result is that the maximum radiation intensity zero-order peak is obtained as this central peak, as evidenced by the spike p shown in the interferogram of FIG. 3. With a Michelson type interferometer, the central peak affords a convenient reference point from which elapsed time measurements can be made as hereinafter described, although it will be understood that any established reference point in time is equally practicable.

Now, if one of the mirrors **30**, **31**, in this case mirror **30**, is moved relative to the other mirror so as to vary the length of light paths of input radiation **23**, it will be seen that, at one point of leftward movement, i.e., at a distance equal to one-half the optical path difference, b, introduced by film **10** out of equality length of the interferometer arms, as viewed in FIG. 2, mirror **30** will shorten the path length of radiation R_2 emanating from the rear-reflective surface of film **10** via points S and T, so that there will be created another zero-order peak g_1, FIG. 3, at which the source path length will be brought into exact equality with the source path length of radiation R_1 emanating from point Q and reflected back to beam splitter **32** from mirror **31**. This sideband peak, compared with central peak p, is of reduced intensity, because it lacks the superadded constructive interference contributed by the remaining two of the total of four radiation wave trains; nevertheless, it is clearly distinguishable above the adjacent noise and incidental uninterpretable complex partial interference signal level, so as to constitute a second point in time upon which to predicate measurement according to this invention.

A second side-band peak of exactly the same amplitude as g_1, namely g_2, is brought into existence on the opposite side of central peak p as a result of the same magnitude of rightward movement of mirror **30** with respect to beam splitter **32**, because the path length of radiation R_1 to mirror **30** is then ultimately lengthened until it is brought into equality with R_2 radiation reflected back from mirror **31**. Therefore, this third zero-order peak affords still another distinctive point in time with respect to either central peak p, side-band peak g_1 or, in fact any other convenient established reference point permitting measurement according to this invention.

Precise control of the translational movement of mirror **30** is, of course, necessary to accurate time measurements and a convenient drive is that provided by saw-tooth oscillator **37** of FIG. 2, which reciprocates the mirror along a time-distance path which is represented by the course line m drawn in as an overlay on the interferogram

ly disposed with respect to zero-order peak p for purposes of this description but it will be understood that there exists a wide choice in this regard. For simplicity in the time measurment of intervals such as Δt drawn between central peak p and side-band peak g_2, it is preferred to maintain the velocity of translation of mirror **30**, i.e., the slope of course line m, constant throughout its scan of the corresponding distance interval, so that the brief mirror return periods, corresponding to terminal traces m' and m'', are deliberately disposed to left and right of sideband peaks g_1 and g_2, respectively.

Quantitatively, the intensity of radiation I_1 seen by photoelectric detector **33** can be expressed as a function of optical path difference overtake r as the product of the intensity distribution from the film and from the interferometer, summed over all of the existing frequencies, by the equation

$$I_1(r)=I_0\Sigma_c \cos^2 \pi cb \cos^2 (\pi cr) \quad (4)$$

where I_0, the source of radiation, is assumed constant and $c=1/\lambda$ is the wave number of the radiation employed. A plot of intensity of photoelectrically perceived radiation in the region of interest is that given by the interferogram of FIG. 3 already elaborated.

Analyzing the travel of mirror **30** throughout one-half of its course only, if the course line m is reproduced somewhat schematically, together with its associated terminal portion m', as shown in FIG. 4, time, plotted as the abscissa, is related to mirror **30** travel in terms of resulting optical path difference overtake r, as ordinate as depicted.

Assuming that one of the zero-order peaks g_1 (or g_2) occurs when mirror **30** is at the inflection ordinate B of its traverse course, the mirror travel between this peak and central zero-order peak p would need to be only $B/2$ since the light reflection path between beam splitter **32** and mirror **30** is a double-length course, extending, as it does, from the splitter to the mirror and back again. Thus, the constant velocity V of mirror **30** throughout the scan from central peak p to a given side-band peak, either g_1 or g_2, is $V=B/2T$, where T is the corresponding constant velocity time interval stepped off along the abscissa, and the rate of optical path difference overtake is then B/T.

The elapsed time interval Δt, between adjacent zero-order peaks is the optical path difference b, in the film divided by the rate of optical path difference overtake, B/T, so that, substituting from Eq. 1,

$$\Delta t=\frac{2n/T \cos \theta_1}{B} \quad (5)$$

or, rearranging terms, d, the film thickness, is a function of elapsed peak-to-peak time, Δt, according to the relationship

$$d=\frac{B(\Delta t)}{2n/T \cos \theta_1} \quad (6)$$

Accordingly, determining the elapsed time, Δt gives a direct measure of film thickness d, subject of course, to the fact that mirror **30** must be at least as great as the maximum optical path in the film, unless the reference point chosen is predeterminedly displaced in a direction narrowing the analytical span, as is usually preferred, since cycle times can then be correspondingly reduced and a larger number of thickness gagings accomplished within a given period of time.

Another design of interferometer, adapted to produce only a single zero-order interference fringe, is that detailed in FIG. 5. Here the film **10'** is viewed by input radiation **15'** impinging on both the front and back radiation-reflective surfaces in the same manner as taught for FIG. 1, with reflection as output radiation indicated schematically as a first-reflected portion **23'** and a second-reflected portion **23''**, which are routed to a plane-surfaced optical plate **42**.

Plate **42** is provided with a first light-reflective coating, such as vaporized aluminum or a similar material, over a limited expanse of the front face **43** interposed across the path of radiation **23''** solely, and with a second light-reflective coating **44** over a small expanse on the rear side of the plate interposed across the path of radiation **23'** solely. Under these circumstances the two wave trains are redirected along courses which bring them into impingement on a radiation detector **33'**, which can be identical in design with detector **33** hereinbefore described.

The scan traverse of plate **42** is obtained by mounting the plate for oscillation around a pivot point D such that the length of path of one beam of reflected radiation, in this instance beam **23''**, is maintained fixed. Whenever the angles of incidence of the radiation on the film and the plate are equal and the optical path differences BCH within film **10'** and EFG for beam **23'** within plate **42** are also equal, as occurs periodically during the cyclic oscillation of plate **42** around pivot D, a zero-order peak is obtained. The necessity for extreme precision in the mirror disposition on plate **42** can be lessened, if desired, by simply half-silvering the entire front mirror face and full-silvering the entire back face.

The reference point constituting the other of the two time interval indicia upon which measurement is based can then conveniently be any chosen point in the oscillatory movement of plate **42** suitably spaced in time from the zero-order peak and signalled as to arrival by the delivery of an electric pulse, which electric pulse output is thus synchronized in time with the cyclic movement of plate **42**.

Typical electrical apparatus for carrying out the method of this invention is shown somewhat diagramatically in FIGS. 6A and 6B, both of which employ conventional pulse-type on-off counters for effecting elapsed time measurement between a zero-order peak and a reference point, but the latter of which dispenses with a clock pulse generator as the time base provider. The first embodiment to be described employs a single, relatively broad-spectrum radiation source **16'** whereas the other embodiment utilizes a broad-spectrum source **16''** in conjunction with a monochromatic source **47**, both operating in the radiation transmissive mode, i.e., with the specimen in examination interposed between the source and the interferometer.

Thus, referring to FIG. 6A, the interferometer indicated generally at **26'** can be identical with that detailed in FIG. 2, including a photosensitive detector (not shown) as integral component. The detector generates a continuous fluctuating voltage signal, such as that shown in FIG. 3, which contains distinctive voltage spikes p and g_1, g_2 characteristic of the central peak and each side-band peak, respectively, as hereinbefore described. To render the response insensitive to the noise and spurious signal readout occupying the interval between successive peaks, resort is had to a conventional pulse-height discriminator **48**, the output of which is limited strictly to pulses of magnitude inclusive of p and g_1, g_2, with all else barred. Under these circumstances, either pair of the pulses p, g_1 or p, g_2 can be employed for measurement of the time interval Δt, FIG. 3, because p is a fixed reference point from which the separation of either sideband peak can be precisely established.

The art of pulse interval measurement is well-advanced, as is described in "Instruments and Control Systems," pp. 125–128, September 1962 issue, published by The Instruments Publishing Company, and requires only an on-off pulse counter, such as that indicated generally at **49**, which embodies a continuously operating clock-pulse generator **50** (typically, a one Mc. oscillator), delivering a constant frequency pulse output **51**, which is thereafter selectively gated by AND gate **52**, so that there is passed to counter **54** a regular pulse train **53** only during the preselected scanning span interval p-to-g_1 or p-to-g_2 upon which time interval measurement is based. Thus, there is AND'ED in gate **52** an Input Trigger Channel **56** actuated exclusively by the counter start signal, which can be either the sensed preception of p or g_1 or

g_2 as desired, although the reference point p is usually preferred because of its fixed location in time. The circuit is completed by an identical Input Trigger Channel 57, reserved to counter stop signal input, which is actuated exclusively by the other zero-order peak of the pair chosen for measurement. Time is then indicated by the registration accumulated in decimal counting units 58 and, if desired, a record printed out, as is standard practice.

The apparatus detailed in FIG. 6B is, in many respects, similar to that of FIG. 6A, except that the time base provider is now a monochromatic source 47, typically a green colored visible light type emitting radiation of about 5000 A. wave length. This radiation is superimposed on the radiation from broad-band source 16" by employment of a transmitting-reflecting mirror 60, so that two distinctive radiation inputs pass to interferometer 26", that received from source 16" providing the zero-order peaks p and g_1, g_2 already described, whereas that from source 47 affords a constant (and relatively high) frequency interference fringe development during the cyclic span traverse of the interferometer. For example, a 5000 A. source 47 was employed in conjunction with a 60 c.p.s. interferometer sweep frequency and a 15 mil sweep span of travel of mirror 30. The central peak-to-side-band-peak spacing for a 10 mil thick film is such that approximately 760 interference fringes are developed from the particular source 47 used, thereby affording a convenient time base. This, of course, occurs simultaneously with the development of the zero-order peaks p, g_1 and g_2 based on radiation from source 16" viewing the film as hereinbefore described.

It is practicable, then, to use a conventional pulse filter 61 as a diverter of the high frequency component of interferometer output to AND gate 52', identical with gate 52 of FIG. 6A, providing a constant frequency time base substitute for clock-pulse generator 50, whereas the zero-order peak pulse signal informative of film gage passes on to pulse-height discriminator 48' and thence to a start signal input trigger channel 56' and a stop signal input channel 57' (neither detailed) identical with the corresponding components of FIG. 6A. Again, the time interval duration is registered in on-off counter 54', exactly as taught for FIG. 6A.

A particularly useful embodiment of this invention, especially suited to on-the-fly gage control by human intervention in a film manufacturing plant, is that shown in FIGS. 7A and 7B. Here it is desirable to continuously indicate visually the variation of film away from nominal processing thickness, so that the operator can take immediate corrective steps or, alternatively, monitor the process in terms of sensed gage variation over a considerable period of time, all as his experience and the specification requirements dictate.

The optical portion of the apparatus is represented schematically within broken-line box 65, whereas the associated electrical assemblage is shown within box 66. The general arrangement is similar to that already described for FIG. 1, with the running film 10', trained about rolls 11' and 12', being viewed in the reflection mode from the right. Again, radiation source 16"' can be a tungsten filament incandescent bulb, operated by D.C. current from a power source not shown, emitting radiation in the wave length range from 1–3 microns. Reflecting-transmitting mirror 67, oriented at an angle of 45° with respect to film 10', is employed to direct source radiation to the film and thereafter receive reflected radiation therefrom, which is then passed to an interferometer of the same type as that shown in FIG. 2, incorporating a fixed mirror 31' and a reciprocatory mirror 30', between which is interposed a reflecting-transmitting mirror type beam splitter 32' which directs the radiation output to photosensitive radiation detector 33', typically a lead sulfide photocell which possesses a maximum gain in the 1–3 micron region.

Mirror 30' is driven in reciprocal saw-tooth mode, 68, as hereinbefore described for the apparatus of FIG. 2, employing a conventional saw-tooth oscillator 70 with associated amplifier 71 as the power source for the conventional electrodynamic motor 72, similar in construction to the voice-coil and magnet structure of a cone-type loudspeaker, which motor has its shaft direct-connected to mirror 30'.

The output voltage signal from radiation detector 33' is passed to preamplifier 75, which can be of the type detailed in FIG. 15.1 and pages 197–198 of "Transistor Circuit Design," published by Texas Instruments, Inc. The amplified voltage output then goes to conventional attenuator 76, which can be of the T-type with 6K ohm characteristic impedance, so as to determine the current drive into the following post amplifier 77 with a constant input voltage. Attenuator 76 can have the circuit shown generally in FIG. 4.13(b), page 123, "Millimicrosecond Pulse Techniques," by Lewis and Wells, publishers McGraw-Hill Book Company, whereas post amplifier 77 is preferably a fixed-gain operational amplifier of the type shown in FIG. 14.1, page 193, "Transistor Circuit Design" supra.

The output next passes into voltage doubler 78, which can have the design shown in FIG. 13–9, described at pages 280–1, "Electron Tube Circuits" by Samuel Seely, publishers McGraw-Hill Book Company, thereby providing a trigger signal of waveform III, FIG. 7B, applicable to bistable multivibrator 79, which can be of the two-transistor D.-C. cross-coupled flip-flop type shown in FIG. 6–5, page 101, "Transistor Circuit Handbook" by L. E. Garner, published by Coyne Company. An indicating meter 80 is connected between the two collectors of multivibrator 79, to give spot indication of film thickness, whereas a gage recorder 81 is connected in parallel from multivibrator 79 to give a continuous record of film gage versus time. Finally, there is provided a wave form alternation connection 83 running from oscillator 70 to multivibrator 79, in circuit with the latter so as to alternate it from one stable state to the other, as depicted by waveform II, FIG. 7B, responsive to flyback of the oscillator output, indicated as waveform I.

The embodiment of FIGS. 7A–7B was devised to detect gage variation from nominal thickness within a preselected tolerance range and, accordingly, it is advantageous to introduce a zero offset, dependent on the nominal film thickness being worked with, in other to limit the relative movement of mirror 30' with respect to mirror 31', to thereby operate with a restricted span of reduced path length, preferably only that region inclusive of the applicable tolerance limits. The investigatory range is thus quite closely confined to the region of allowable film thickness variation only, without incurring the possibility of any extraneous interference foreign to this region and, at the same time, limiting the investigation to the matter of primary concern, and that only, namely, the distance separating the two film faces.

The appropriate offset can be readily obtained by either altering the fixed mirror 31' mounting an exact distance shortening the path from beam splitter 32' to it in order to match the critical distance reached in the path of travel taken by mirror 30' during its reciprocatory travel or, alternatively, the mounting of the latter can be shifted, as by a micrometer screw adjustment, in order to achieve the same objective. Thus, while the primary reference still remains the central zero peak as already described with reference to FIGS. 1–4, there is no need to actually traverse that peak in the cyclic scanning so long as the amount of offset deliberately introduced into the mirror 30', 31' placement is known and taken account of.

In operation, a given side-band peak is preselected as the guide-on, so that the radiation input from beam splitter 32' to photosensitive detector 33' carries with it a characteristic side-band zero-order peak resulting from constructive interference, as hereinbefore described.

Typically, for the monitoring of film thicknesses up to about 12 mils, mirror 30' reciprocates at scan rates from about 10 to 160 cycles per second over travels ranging, respectively, from only 2.5 mils to 0.15 mil, depending upon the tolerance which is to be maintained. The higher the frequency of the scan rate, the greater the number of measurements of film thickness it is possible to make during a given interval of time.

The voltage signal from detector 33' is amplified by preamplifier 75 and then passed to attenuator 76. The attenuator provides a stepped, switch-controlled, manual gain adjustment enabling operator choice of the signal level over the range of film thicknesses measured. Preferably, attenuator 76 permits signal level attenuation in the range of unity down to about 0.01.

The output signal is then post-amplified in amplifier 77, following which it is introduced into voltage doubler 78, which provides the trigger signal depicted as waveform III, FIG. 7B, applied to multivibrator 79. The time relationship of operations is best understood by consideration of FIG. 7B, which shows the several waveforms involved in common time synchronism.

Thus, waveform I is the saw-tooth voltage generated by oscillator 70, this triggering multivibrator 79 via circuit connection 83 so as to switch it, at constant frequency, from one stable state to the other at the instant of flyback, thereby providing the time base waveform II. When a trigger signal in the form of the successive spikes of waveform III is received by multivibrator 79 from voltage doubler 78, the multivibrator output is converted to waveform IV, i.e., reversal of polarity is induced as a result of receipt of a signal corresponding to the encountering of a side-band zero-order peak, so that an averaging of the top and bottom halves of waveform IV by the meter 80 connected between the two collectors of multivibrator 79 provides a reading indicative of film thickness variation from nominal thickness.

From the foregoing, and reference to FIG. 7B, it will be understood that the duration of one half cycle of waveform II constitutes the time base upon which pulse III, the index of film thickness, is superimposed, so that exact centering of perceived pulse III, as shown in FIG. 7B, confirms that actual nominal thickness is being measured. Conversely, movement of pulse III to right or left of the center point, as viewed in FIG. 7A, which center point is determined by calibration from a standard film specimen of known gage, reveals, respectively, that the film is thicker or thinner than the nominal value. Recorder 81, connected in parallel with indicating meter 80, records the running gage variance from nominal and thus enables the operator to verify the effects of any corrective measures he may take responsive to spot readings had on meter 80.

In practice it is often desirable to traverse the film to obtain a thickness profile across the entire width. This is readily accomplished with the apparatus of this invention by mounting the optical apparatus 65, FIG. 7A, within a compact scanning head on the end of a reciprocatory-driven telescopic boom, effecting connection to the electrical components 66 via a flexible cable. In a typical example, polyester film ranging in thickness from 0.1 mil to 12 mils in the various grades produced was the product. Moderate haze in the film affected the transparency, so that the radiation transmission was in the range of approximately 30% to 100%. The running film speed was 50 ft./min., with the usual film width in excess of 3 ft. Operating in the reflection mode with normal light incidence on the film, a vertical film flutter movement of as much as 6–8" in a 12 ft. width could be tolerated without noticeable effect on film thickness measurement.

With a clearance between the optical head and the film of 18", the radiation inspection spot measured about ¼" x ¼". A single traverse of the gage across a 10 ft. width of film required, typically, approximately 3 mins., giving a profile of film thickness extending over a diagonal path of length dependent on film speed. The results obtained were very satisfactory and the apparatus proved to be a valuable aid to manufacturing control.

Referring back to Equation 5 hereinbefore set forth, time interval Δt is seen to be a function of refractive index n as well as length of path d, so that this invention also affords a means for measuring refractive index as well.

A preferred apparatus for the accomplishment of this is portrayed somewhat schematically in FIG. 8. Here the sample 86, of thickness d, can be a running film, a flowing liquid sample or any other physical form of material reflecting radiation from its surfaces as hereinafter described.

The optical arrangement employed is similar to that shown in FIG. 1, except that two interferometric examinations are here made simultaneously, one being normal to the sample, as to which the radiation course is indicated in full-line representation in FIG. 8, whereas the other is at an angle θ to the normal, which radiation course is shown in broken-line representation. This is conveniently accomplished by use of a common source 87 employing focusing lenses 18' and 18", the former of which directs radiation to beam splitter 90, which reflects essentially all of it along course 92 perpendicular to the sample surface, whereas the latter directs radiation at an angle of typically 45° thereto, shown as course line 85. A portion of the normal radiation is reflected back through beam splitter 90 from both the front and rear surfaces of sample 86, and thence to interferometer 91, which can be identical in design with that already taught with respect to FIG. 2. The radiation impinging angularly of sample 86 is reflected from the front surface along a course 88, whereas a portion is refracted internally of the sample along a course making an angle of θ_1 with the normal, to thereafter be reflected from the rear surface and thence leave the sample along course 89. Both of these radiation components are reflected via mirror 93 to beam splitter 90, and thence to interferometer 91.

From the foregoing, it will be understood that there are four separate wave trains available for development of zero-order peaks, the central peak p', FIG. 9, resulting from constructive interference between all four wave trains when the reciprocatory mirror of interferometer 91 arrives at a point in its travel wherein the two interferometer arms are exactly equal. On the other hand, as the reciprocatory mirror moves farther in its reciprocation, side-band zero-order peaks result from constructive interference occurring sequentially as regards radiation impinging normally of the sample along course line 92, i.e., h_1, and as regards radiation impinging angularly of the sample along course line 85, i.e., h_2. Side-band zero-order peaks h_1 and h_2 are spaced apart 1–1.5% of the extreme central peak-to-side-band peak span, but are distinctive enough to permit ready measurement of the time intervals Δt_1 and Δt_2 upon which refractive index measurement can be predicated.

Thus, by Equation 5 hereinbefore set forth, $\Delta t_1 = K(2nd)$ cos θ_1, where $K = T/B$, but, since θ_1 for radiation of normal incidence is zero degrees, cos $\theta_1 = 1$, and, therefore, $\Delta t_1 = K(2nd)$. Similarly, $\Delta t_2 = K(2nd)$ cos θ_1; however, θ_1 in this case is the angle of refraction shown in FIG. 8, which is greater than zero for the angularly incident radiation. Combining the equations, $\Delta t_2 = \Delta t_1$ cos θ_1, or cos $\theta_1 = \Delta t_2/\Delta t_1$, and this ratio of the two applicable time measurements can be easily obtained by conventional voltage analog means.

By Snell's Law, sin $\theta_1 = \sin \theta/n$, where n = refractive index. Using the trigonometric relationship

$$\sin^2\theta_1 + \cos^2\theta_1 = 1$$

and substituting sin θ/n for sin θ_1, the equation

$$n \cos \theta_1 = \sqrt{n^2 - \sin^2\theta}$$

results, whereupon, sin θ being known and cos θ_1 being determined as the time interval $\Delta t_2/\Delta t_1$ ratio, the refractive index can be computed.

Many polymeric materials display the property of birefringence in varying degrees, depending upon the extent of molecular orientation which exists within the crystals. Thus, each crystal will possess three distinctive refractive indices n_x, n_y and n_z, orthogonally related to each other. Birefringence in the length (x)–width (y) plane for thin sheets is then defined as $|n_x-n_y|$. If a film exhibiting birefringence is examined with normally incident radiation in exactly the same manner as hereinbefore taught for film gage measurement, twin side-band peaks k_1 and k_2 are obtained, as shown in FIG. 10. Again, the time intervals Δt_1 and Δt_2 found to exist in scanning from central peak p'' to side-band peaks k_1 and k_2, respectively, can be measured. In operation, as will be clear from the discussion of Equation 5 as applied to normal incidence examinations for the determination of refractive index hereinbefore set forth, optical thickness, defined as the product of a given refractive index n and film thickness d, is related to the time interval Δt by a common constant K', so that, as a generality, $\Delta t=K'nd$.

Then, $\Delta t_2'-\Delta t_1'=K'n_xd-K'n_yd$. If the latter expression is divided by the product of K' times an average thickness $d_{(ave)}$, one obtains birefringence, that is:

$$\left|\frac{K'n_xd-K'n_yd}{K'd_{(ave)}}\right|=\left|n_x-n_y\right| .$$

The average thickness, $d_{(ave)}$, employed here is not particularly critical to the calculation, as long as it is generally within the range of values measured in the gage monitoring already described. Conveniently, the film gage can be measured simultaneously with the birefringence, the same side-band k_1 and k_2 peaks being employed as indicia, and thickness being then taken as the average based upon a time interval immediate $\Delta t_1'$ and $\Delta t_2'$, if extreme accuracy is desired.

Various other properties, such as the presence of particular substances in the product and many other factors, are often accompanied by characteristic radiation interference effects which can be measured and correlated with the causative agency, provided their effects can be isolated, through the use of this invention, and it is, accordingly, intended to be limited only by the scope of the following claims:

I claim:

1. A method for determining a physical property of a specimen on the basis of interferometric optical phase discrimination comprising, in sequence, directing analytical radiation upon said specimen along a course such that there is developed an optical phase difference between radiation emanating from a first radiation-reflective surface of said specimen and from a second radiation-reflective surface of said specimen, cyclically varying at a predetermined time rate the length of the path of travel of said radiation emanating from a given one of the pair consisting of said first radiation-reflective surface of said specimen and said second radiation-reflective surface of said specimen, with respect to the length of the path of travel of the radiation emanating from the other of said pair over a span inclusive of a zero-order peak at which there exists constructive interference between said radiation emanating from said first radiation-reflective surface of said specimen and from said second radiation-reflective surface of said specimen, measuring the elapsed time existing between the scan traverse of said zero-order peak at which there exists said constructive interference and a preselected reference point synchronized in time with the cycle of said scan traverse, said preselected reference point being originally established in location by scanning said specimen through a span inclusive of a central zero-order peak, and determining said physical property of said specimen as a function of said elapsed time.

2. A method of determining a physical property of a specimen on the basis of interferometric optical phase discrimination according to claim 1 wherein said preselected reference point is a second zero-order peak at which there exists constructive interference between said radiation emanating from both said first radiation-reflective surface of said specimen and from said second radiation-reflective surface of said specimen individually.

3. A method of determining the thickness of a radiation-transmissive film on the basis of interferometric optical phase discrimination according to claim 1 wherein said first radiation-reflective surface is one external face of said film and said second radiation-reflective surface is the other external face of said film.

4. A method of determining a physical property of a specimen on the basis of interferometric optical phase discrimination according to claim 1 wherein the length of said path of travel of said radiation emanating from said given one of said pair consisting of said first radiation-reflective surface of said specimen and said second radiation-reflective surface of said specimen is cyclically varied at a substantially constant time rate whereas said path of travel of said radiation emanating from the other of said pair is maintained fixed in length.

5. Apparatus for determining a physical property of a specimen on the basis of interferometric optical phase discrimination comprising, in combination, a source directing radiation upon said specimen of a wavelength adapted to develop an optical phase difference between radiation emanating from a first radiation-reflective surface of said specimen and from a second radiation-reflective surface of said specimen, means cyclically varying at a predetermined time rate the length of the path of travel of said radiation emanating from a given one of the pair consisting of said first radiation-reflective surface of said specimen and said second radiation-reflective surface of said specimen with respect to the length of the path of travel of the radiation emanating from the other of said pair over a span inclusive of a zero-order peak at which there exists constructive interference between said radiation emanating from said first radiation-reflective surface of said specimen and from said second radiation-reflective surface of said specimen, means sensing the occurrence of said zero-order peak, means measuring the elapsed time existing between the scan traverse of said zero-order peak and a preselected reference point synchronized in time with the cycle of said scan traverse, said preselected reference point being originally established in location by scanning said specimen throughout a span inclusive of a central zero-order peak, and means indicating said physical property of said specimen as a function of said elapsed time.

6. Apparatus for measuring a physical property of a specimen on the basis of interferometric optical phase discrimination according to claim 5 wherein said means cyclically varying at a predetermined time rate the length of the path of travel of said radiation emanating from a given one of the pair consisting of said first radiation-reflective surface of said specimen and said second radiation-reflective surface of said specimen with respect to the length of the path of travel of the radiation emanating from the other of said pair consists of a Michelson-type interferometer having one of its mirrors fixed and the other mirror provided with reciprocatory drive means moving said last-mentioned mirror over said span inclusive of a zero-order peak at which there exists constructive interence between said radiation emanating from said first radiation-reflective surface of said specimen and from said second radiation-reflective surface of said specimen.

7. Apparatus for measuring a physical property of a specimen on the basis of interferometric optical phase discrimination according to claim 5 wherein said means measuring said elapsed time existing between said scan traverse of said zero-order peak at which there exists said constructive interference and said preselected ref-

erence point synchronized in time with the cycle of said scan traverse consists of an electrical pulse counter operating responsive to a pulse source generating electrical pulses at a time rate high in comparison with the time required for said scan traverse, provided with switching means starting counting by said counter at the sensing of said preselected reference point and halting said counting at the sensing of said zero-order peak.

References Cited by the Examiner

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JEWELL H. PEDERSEN, *Primary Examiner.*

JOHN K. CORBIN, *Examiner.*

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

BIO-RAD LABORATORIES, INC., a Delaware corporation, *Plaintiff,* v. NICOLET INSTRUMENT CORP. a Wisconsin corporation, *Defendant.*	CIVIL ACTION NO. C81-2553 LHB FORM OF VERDICT (PATENT)
NICOLET INSTRUMENT CORP., a Wisconsin corporation, *Counterclaimant,* v. BIO-RAD LABORATORIES, INC., a Delaware corporation, *Counterdefendant.*	

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UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

FORM OF VERDICT
(PATENT)

QUESTION NO. 1

Are Claims 1-7 of the Flournoy Patent No. 3,319,515 asserted by Bio-Rad against Nicolet valid or invalid?

(Indicate by checkmarks)

	Invalid	Valid
CLAIM 1	_____	✓
CLAIM 2	_____	✓
CLAIM 3	_____	✓
CLAIM 4	_____	✓
CLAIM 5	_____	✓
CLAIM 6	_____	✓
CLAIM 7	_____	✓

QUESTION NO. 1A

If any of the above claims are invalid, was your decision based upon one or more of the following:

(Indicate by checkmark(s)):

	Yes	No
a. Improper Inventor (Instruction No. 24)	_____	_____
b. Failure to disclose material fact(s) to the Patent Office. (Fraud on the Patent Office) (Instruction No. 46)	_____	_____
c. Lack of novelty (Instruction Nos. 27, 29)	_____	_____
d. Obvious in view of prior art (Instruction Nos. 30-38)	_____	_____

	Yes	No
e. Inoperative disclosure (Instruction Nos. 14, 26)	_____	_____
f. Failure to disclose best mode (Instruction No. 14)	_____	_____
g. Failure to particularly point out and distinctly claim the invention (Instruction No. 16)	_____	_____

If you in your answer to Question No. 1, any of the claims of the Flournoy patent are valid, then answer Question No. 2.

QUESTION NO. 2

Does the Nicolet MX-ECO infringe any valid claims of the Flournoy Patent No. 3,319,515?

(Indicate by checkmarks)

	Not Infringed	Infringed
CLAIM 1	_____	✓
CLAIM 2	_____	✓
CLAIM 3	_____	✓
CLAIM 4	_____	✓
CLAIM 5	_____	✓
CLAIM 6	_____	✓
CLAIM 7	_____	✓

QUESTION NO. 3

If you find that any of the claims of the Flournoy patent are valid and infringed, what total amount of money damages should be assessed against Nicolet for the infringement?

$3,078,000.00

QUESTION NO. 4

Was Nicollet's infringement willful and deliberate?

ANSWER "Yes" or "No"

ANSWER NO

QUESTION NO. 5

If the answer to Question No. 4 is "Yes", state the total award which should be assessed against Nicolet (not to exceed 3 times the amount of damages listed in the answer to Question No. 3 above)

Dated: December 23, 1982

/s/ Gene S. Mori

FOREPERSON

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

BIO-RAD LABORATORIES, INC. a Delaware corporation *Plaintiff,* v. NICOLET INSTRUMENT CORP., a Wisconsin corporation, *Defendant.*	CIVIL ACTION NO. C81-2553 LHB

FINAL JUDGMENT

This action came on for trial before the court and a jury, Honorable Lloyd H. Burke, District Judge, presiding, and the issues having been duly tried and the jury having duly rendered its verdict, it is Ordered and Adjudged:

1. That claims 1-7 of U.S. Patent No. 3,319,515 are each valid.

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WILLIAM L. WHITTAKER
CLERK, U.S. DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA

2. That Defendant Nicolet Instrument Corporation ("Nicolet") has infringed claims 1-7 of said U.S. Patent No. 3,319,515 by making, using, and selling "MX-ECO" interferometric epitaxial film thickness gauges.

3. That Plaintiff, Bio-Rad Laboratories, Inc. ("Bio-Rad") shall recover of defendant Nicolet as compensatory damages the sum of Three Million Seventy-Eight Thousand Dollars ($3,078,000.00), with interest thereon as provided by law, said interest to be accrued from January 7, 1983.

4. That Plaintiff Bio-Rad shall further recover its costs of the action.

5. That Defendant Nicolet's counterclaims against plaintiff Bio-Rad are hereby dismissed with prejudice.

SO ORDERED.

Date: 18 Jan. 1983

/s/Lloyd H. Burke

Hon. Lloyd H. Burke
U.S. District Judge

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

BIO-RAD LABORATORIES, INC., a Delaware corporation, *Plaintiff,* v. NICOLET INSTRUMENT CORP., a Wisconsin corporation, *Defendant,*	CIVIL ACTION NO. C81-2553 LHB

PERMANENT INJUNCTION

This action came on for trial before the court and a jury, Honorable Lloyd H. Burke, District Judge, presiding, the issues having been duly tried and the jury having duly rendered its verdict, judgment for Plaintiff having been duly entered on January 19, 1983, and the court having heard and duly considered Plaintiff's Motion for a Permanent Injunction and the evidence adduced at trial, it is Ordered, Adjudged and Decreed as follows:

Defendant, Nicolet Instrument Corporation ("Nicolet") its officers, agents, representatives, employees, servants, attorneys, are hereby permanently enjoined and restrained, until expiration of U.S. Patent No. 3,319,515 on May 16, 1984, or until

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WILLIAM L. WHITTAKER
CLERK, U. S. DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA

written order of this court, from engaging in activities which infringe, or induce others to infringe, one or more claims of U.S. Patent No. 3,319,515 in any way, such as making, using, or selling the "MX-ECO" interferometric epitaxial film thickness gauges, the structure and operation of which are described and represented in:

(a) Plaintiff's Exhibit A-232, an operational manual;
(b) Plaintiff's Exhibit A-213, a brochure; and
(c) Plaintiff's Exhibit A-267, software listing.

SO ORDERED,

Date: February 4, 1983.

/s/Lloyd H. Burke

Hon. Lloyd H. Burke
U.S. District Judge

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

BIO-RAD LABORATORIES, INC., a Delaware corporation, *Plaintiff,* v. NICOLET INSTRUMENT CORP., a Wisconsin corporation, *Defendant,*	CIVIL ACTION NO. C81-2553 LHB

FLEHR, HOHBACH, TEST
ALBRITTON & HERBERT
DOCKETED
FEB 7 1983
BY
RESPONSE DUE 3-7-83

ORDER SUSPENDING INJUNCTION
PENDING APPEAL

This cause came on to be further heard on motion of Defendant, Nicolet Instrument Corporation ("Nicolet") for a suspension, pending appeal by Nicolet, of the Permanent Injunction heretofore entered against Nicolet and enjoining Nicolet from infringing U.S. Patent No. 3,319,515. After having heard the arguments of counsel and noting that Nicolet appears to be financially sound, the court has determined that it is in the public interest that Nicolet be permitted, pending said appeal, to sell or otherwise dispose of products, including the instrument known as the "MX-ECO", which infringe said patent because said patent will expire May 16, 1984, and the public, having exhibited a marked preference for the MX-ECO over the Plaintiff's FTG-12, should not be deprived of such products sold by Nicolet, including the MX-ECO, during the pendency of said appeal or until said patent expires, whichever occurs first.

THEREFORE, IT IS ORDERED that said Permanent Injunction be and it hereby is suspended pending said appeal: PROVIDED that Nicolet shall execute bond, with sufficient surety,

to be approved by the court, in the amount of $300,000.00 on or before February 14, 1983, conditioned that said bond shall be used for the satisfaction of any and all damages (or such portion thereof/s/LHB) suffered by Plaintiff, Bio-Rad Laboratories, Inc. as a result of the sale or other disposition by Nicolet of instruments, including but not limited to the MX-ECO, which infringe said patent, subsequent to December 23, 1982, the date of the jury verdict.

/s/Lloyd H. Burke

Dated: February 4, 1984

Hon. Lloyd H. Burke
U.S. District Judge

UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA

BIO-RAD LABORATORIES, INC., a Delaware corporation, *Plaintiff,* v. NICOLET INSTRUMENT CORP., a Wisconsin corporation, *Defendant,*	CIVIL ACTION NO. C81-2553 LHB

ORDER DENYING DEFENDANT'S MOTIONS UNDER FED. R. CIV. P. 50(b) AND 59 FOR JUDGMENT NOTWITHSTANDING THE VERDICT AND IN THE ALTERNATIVE FOR A NEW TRIAL IN ITS PATENT AND ANTITRUST CASES, AND DENYING DEFENDANT'S MOTION FOR THE COURT TO DENY ENFORCEMENT OF THE PATENT IN SUIT UNDER THE DOCTRINE OF PATENT MISUSE

The Defendant, Nicolet Instrument Corporation, having filed motions for judgment notwithstanding the verdict and, in the alternative, for a new trial as to both the Plaintiff's action for patent infringement and the Defendant's counterclaim for antitrust, pursuant to Federal Rules of Civil Procedure, Rules

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WILLIAM L. WHITTAKER
CLERK, U. S. DISTRICT COURT
NORTHERN DISTRICT OF CALIFORNIA

50(b) and 59, and having simultaneously filed a motion to deny enforcement of U.S. Patent No. 3,319,515 on the basis of patent misuse; and this Court having red the Defendant's briefs in support thereof and Plaintiff's briefs in opposition, having heard the arguments of counsel for both parties at a hearing on February 4, 1983, and having given due consideration to the evidence adduced at trial and other pertinent matters of record herein,

IT IS HEREBY ORDERED:

(1) That Defendant's motions for judgment notwithstanding the verdict, as to both the patent and antitrust claims, pursuant to FRCP Rule 50(b), are DENIED;

(2) That Defendant's motions for new trial, as to both the patent and antitrust claims, pursuant to FRCP, Rule 59, are DENIED; and

(3) That Defendant's motion to deny enforcement of the patent by virtue of patent misuse is DENIED.

/s/Lloyd H. Burke

Date: February 8, 1984

Hon. Lloyd H. Burke
United States District Judge
Northern District of California

UNITED STATES COURT OF APPEALS
FOR THE FEDERAL CIRCUIT

BIO-RAD LABORATORIES, INC., a Delaware Corporation	)	Appeal No. 83-829/83-864.
Plaintiff-Appellee, Cross-Appellant,	)	
v.	)	
NICOLET INSTRUMENT CORP. a Wisconsin Corporation	)	
Defendant-Appellant, Cross-Appellee.	)	

DECIDED: July 12, 1984

Before FRIEDMAN, *Circuit Judge*, NICHOLS, *Senior Circuit Judge*, and BALDWIN, *Circuit Judge*.

BALDWIN, *Circuit Judge*.

This is an appeal from an unpublished decision of the United States District Court for the Northern District of California holding claims 1-7 of U.S. Patent No. 3,319,515 (hereinafter '515 patent or Flournoy patent) for an "Interferometric Optical Phase Discrimination Apparatus" valid and infringed. Judgment was entered on a jury verdict rendered after fourty-four days of trial. We vacate the District Court's denial of prejudgment interest and remand for an award of prejudgment interest or a determination that some reason exists for denying prejudgment interest. In all other respects, the judgment is affirmed.

The Parties

Bio-Rad Laboratories, Inc. (Bio-Rad) is a Delaware corporation with its principal office in Richmond, California. Between

1978 and 1979, Bio-Rad acquired two divisions, Digilab, Inc. (Digilab) and Block Engineering, Inc. (Block Engineering). Digilab was formed as a subsidiary of Block Engineering in 1969 to produce and sell instruments that rapidly measure the crystalline surface layer on semiconductors, known as the epitaxial layer. Since 1970, Digilab has manufactured and sold an epitaxial measuring instrument known as the FTG-12 under an exclusive license from E.I. du Pont de Nemours and Company (du Pont), owner of the '515 patent. When Bio-Rad acquired Block Engineering and Digilab, it also acquired the exclusive license under the '515 patent which included the right to enforce the patent against infringers. The name Bio-Rad will be used throughout this opinion to refer to the conduct of Digilab, and Block Engineering, as well as the conduct of Bio-Rad.

Nicolet Instrument Corporation (Nicolet) is a Wisconsin corporation engaged in the production and sale of electronic instruments. In 1979, Nicolet began selling an epitaxial thickness measuring instrument known as the MX-ECO.

Procedural Background

In 1981, Bio-Rad sued Nicolet for willful infringement of the '515 patent by Nicolet's production and sale of the MX-ECO measuring instrument. Nicolet counterclaimed for a declaratory judgment that the '515 patent is invalid and not infringed, and for alleged violations of the antitrust laws.

Both Bio-Rad and Nicolet demanded a jury trial and agreed to submit the case to the jury on general verdicts without special interrogatories. The jury declared all seven claims of the '515 patent valid and infringed, but not willfully infringed. The jury also concluded that Bio-Rad did not violate sections 1 or 2 of the Sherman Antitrust Act. The jury awarded Bio-Rad $3,078,000 in money damages for the infringement.

Nicolet moved for judgment notwithstanding the verdict (JNOV) and, in the alternative, for a new trial. Nicolet also moved to deny enforcement of the '515 patent for misuse.

The district court denied all three motions and denied Bio-Rad's separate request for prejudgment interest. The trial judge entered judgment on the jury verdicts without comment and permanently enjoined Nicolet from infringing the '515 patent in any way, including the production, use or sale of the MX-ECO epitaxial thickness gauge. Interest was awarded from the date judgment was entered.

Nicolet appeals from the judgment entered by the District Court, and from the court's refusal to declare the '515 patent unenforceable for patent misuse. Bio-Rad cross-appeals from the lower court's denial of prejudgment interest. Although this appeal is from the hudgment entered on the jury verdict, the District Court's denial of Nicolet's motions guides our analysis. Accordingly, we consider the issues raised by the parties in the following order:

I. Grounds For JNOV.

II. Grounds For New Trial.

III. Patent Misuse.

IV. Prejudgment Interest.

Standard of Review

Several cases have issued from this court describing the analysis trial judges should follow when they entertain motions for JNOV or new trial. *Connell v. Sears, Roebuck & Co.*, 722 F.2d 1542, 1546, 220 USPQ 193, 197 (Fed. Cir. 1983); *Railroad Dynamics, Inc. v. A. Stucki Co.*, 727 F.2d 1506, 1512-13, 220 USPQ 929, 936 (Fed. Cir. 1984); *Perkin-Elmer Corp. v. Computervision Corp.*, 732 F.2d 888, 221 USPQ 669, 672-673 (Fed. Cir. 1984). That analysis need not be repeated here, but description of our appellate review process is useful.

Nicolet has urged that we review the record *de novo*, in part because no interrogatories were submitted to the jury and because the trial judge did not produce a written opinion

discussing reasons for denying Nicolet's motions or describing the facts supporting the jury verdict. Nicolet mistakes our role. The presence of special interrogatories or a written opinion by the trial court certainly makes our task easier but the absence of these aids does not alter our standard of review. In the absence of special interrogatories we presume the existence of factual findings and legal conclusions necessary to support the verdict reached by the jury. The findings and conclusions are controlled by the court's instructions to the jury. *Perkin-Elmer*, 732 F.2d at 893, 221 USPQ at 673. On appeal after denial of a motion for JNOV, appellant must show either 1) that the jury's presumed or express findings are not supported by substantial evidence, or, 2) if the jury's findings were supported by substantial evidence, that the legal conclusions implied from the verdict cannot be supported by those findings. *Perkin-Elmer*, 732 F.2d at 893, 221 USPQ at 673. In sum, appellant must show either that reasonable jurors could not have made the presumed findings or that the conclusions necessary to the general verdict were not supported. The District Court's denial of Nicolet's Motion for a new trial is reviewed on an abuse of discretion standard. *Railroad Dynamics, Inc.* v. *A Stucki Co.*, 727 F.2d at 1512, 220 USPQ at 935. As this description of our approach demonstrates, our role as a reviewing court is circumscribed by standards that place a difficult burden on appellant.

Analysis

I. Grounds For JNOV

To overturn the District Court's denial of the Motion For JNOV, Nicolet presents several grounds for declaring the '515 patent invalid. The various grounds for invalidity will be discussed under the following lettered sections:

A. Anticipation and Obviousness.

B. Fraud.

C. Compliance With The Requirements Of 35 U.S.C. § 112.

D. Infringement.

A. Anticipation and Obviousness

1. Description of the Invention

The '515 patent claims a method and apparatus determining the thickness of a film or a surface layer on a substrate. The apparatus, known as an interferometer, may be used to measure the thin crystalline surface layer of semiconductors, known as the epitaxial layer. The claimed method is represented by claim 1 of the '515 patent, reproduced below:

> 1. A method for determining a physical property of a specimen on the basis of interferometic optical phase discrimination comprising, in sequence, directing analytical radiation upon said specimen along a course such that there is developed an optical phase difference between radiation emanating from a first radiation-reflective surface of said specimen and from a second radiation-reflective surface of said specimen cyclically varying at a predetermined time rate the length of the path of travel of said first radiation emanating from a given one of the pair consisting of said first radiation-reflective surface of said specimen and second radiation-reflective surface of said specimen, with respect to the length of the path of travel of the radiation emanating from the other of said pair over a span inclusive of a zero-order peak at which there exists constructive interference between said radiation emanating from said first radiation-reflective surface of said specimen and from said second radiation-reflective surface of said specimen, measuring the elapsed time existing between the scan traverse of said zero-order peak at which there exists said constructive interference and a preselected reference point synchronized in time with the cycle of said scan traverse, said preselected reference point being originally established in location by scanning said specimen through a span inclusive of a central zero-order peak, and determining said physical property of said speci-

men as a function of said elapsed time.

5. Apparatus for determining a physical property of a specimen on the basis of interferometric optical phase discrimination comprising, in combination, a source directing radiation upon said specimen of a wavelength adapted to develop an optical phase difference between radiation emanating from a first radiation-reflective surface of said specimen and from a second radiation-reflective surface of said specimen, means cyclically varying at a predetermined time rate the length of the path of travel of said radiation emanating from a given one of the pair consisting of said first radiation-reflective surface of said specimen and said second radiation-reflective surface of said specimen with respect to the length of the path of travel of the radiation emanating from the other of said pair over a span inclusive of a zero-order peak at which there exists constructive interference between said radiation emanating from said first radiation-reflective surface of said specimen and from said second radiaition-reflective surface of said specimen, means sensing the occurrence of said zero-order peak, means measuring the elapsed time existing between the scan traverse of said zero-order peak and a preselected reference point synchronized in time with the cycle of said scan traverse, said preselected reference point being originally established in location by scanning said specimen throughout a span inclusive of a central zero-order peak, and means indicating said physical property of said specimen as a function of said elapsed time.

Operation of a preferred embodiment of the claimed invention is illustrated with reference to Figure 1 from the patent in suit. Film or specimen 10 moves over guide rolls 11 and 12 as it is produced. A beam of light emanates from a light source 16 mounted within housing 17. Light 15 travels through convex lens 18 and is projected as a single beam onto the film 10 by a silvered prism 19.

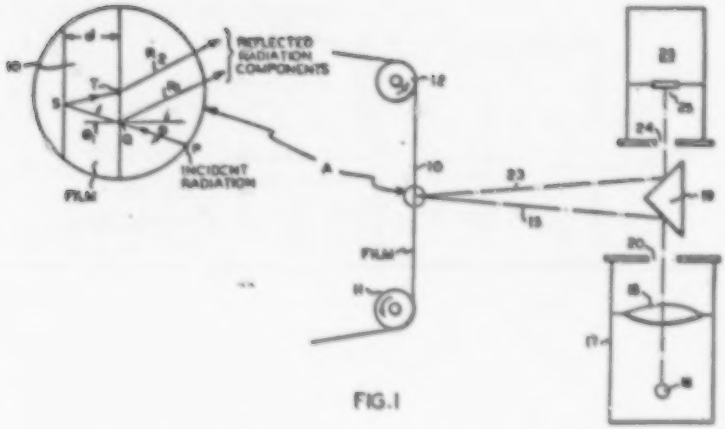

FIG.1

Enlarged inset A shows light 15 impinging upon a front refractive surface of film 10 at Q. A first component of the light is reflected away from the film along R_1, while a second component of the light is transmitted through the film to a back radiation-reflective surface at S. The transmitted component is reflected back along path R_2. Both components of light moving along paths R_1 and R_2 are identified in Figure 1 as 23. The reflected light components traveling along paths R_1 and R_2 are out of phase because of the difference in distance traveled by the first and second components after refraction and reflection. The phase difference results in interference that can be measured by an interferometer.

An interferometer used in appellee's claimed invention known as a Michelson interferometer, is illustrated in Figure 2 of the '515 patent:

As in conventional interferometers, the light 23 strikes an inclined beam-splitter 32 which delivers light to mirrors 30 and 31. The mirrors reflect the light back to beam splitter 32 which

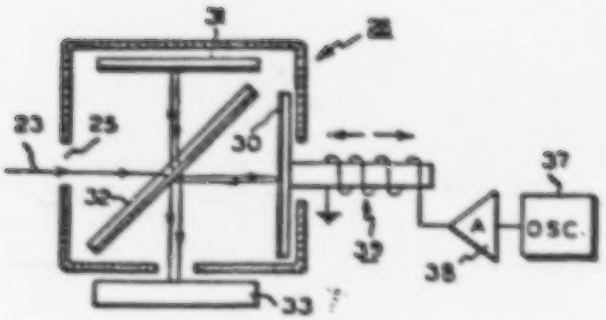

FIG.2

in turn directs the beams towards a photoelectric detector 33. The detector measures the interference between the beams of light. During operation, mirror 30 is reciprocated cyclically over a known distance. The reciprocal motion, or oscillation, is effected by a saw-tooth oscillator 37 and associated electronic power amplifier 38. The mirror 30 oscillates at about 50 cycles/second.

As explained above, the light making up beam 15 is in phase when it reaches the surface of film 10. However, after reflection and refraction, the light traveling along paths R_1 and R_2 are out of phase because of the difference in distance traveled. The differences in distance traveled is related to the thickness of film 10. In the interferometer, a beam splitter divides each of the two components of the light 23 in half, yielding four beams. Two beams are directed to a stationary mirror and the other two to the reciprocating mirror. The mirrors reflect the beam components back to the beam splitter which directs the light to the detector. As the beams emerge from the interferometer together, they interfere with each other. This interference is measured and an interferogram may be produced. The interferogram may look like the interferogram illustrated in Figure

3 of the '515 patent, reproduced below:

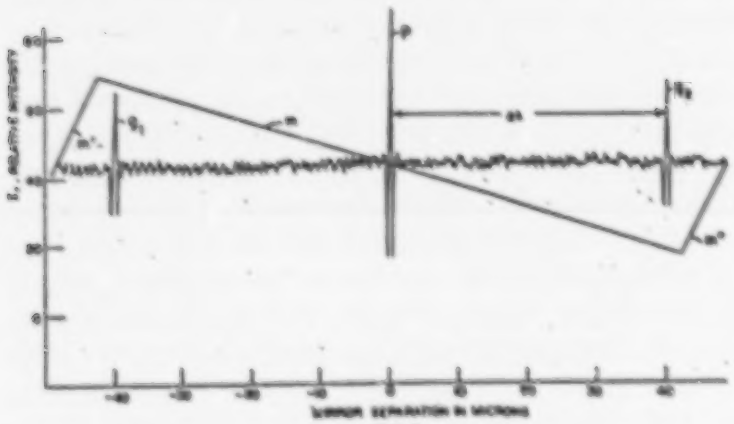

FIG.3

Central peak P is generated when all four beam components interfere constructively. This occurs when the mirrors 30 and 31 are the same distance from the beam splitter 32. Side peaks g_1 and g_2 occur when the difference in the distances between the beam splitter and the two mirrors corresponds to the optical retardation caused by the film. The side peaks are of lesser intensity than the central peak because only two of the beam components are constructively interfering.

The invention claimed in the '515 patent uses the distance between peaks to determine the thickness of the film. Figure 3 shows the "nirror separation in microns." This is the distance the mirror has traveled from the position where the four beams interfere constructively, known as the zero position. The time between the occurrence of two reference peaks may be measured directly from the interferogram to determine the thickness of the film.

2. **Anticipation**

Nicolet argues that the claims, except claim 6, read on a

publication by Lowenstein and are therefore invalid under 35 U.S.C. § 102. Lowenstein used infrared radiation and a lamellar grating interferometer which does not use mirrors that oscillate like those of a Michelson interferometer. Lamellar grating interferometers were used when light in the far infrared was employed because, at the time, there were no efficient beam splitters for light in the far infrared. One measurement or run of the interferometer used by Lowenstein could take six to eight hours. Nicolet's argument is that the substitution of a Michelson interferometer would have been obvious to one of ordinary skill in the art when not working with far infrared radiation. There was also evidence that the Lowenstein article differs from the claimed invention because Lowenstein does not teach the measurement of thin films from peaks of an interferogram. Because of these substantial differences between the claimed invention and the Lowenstein reference, the appropriate analysis is under 35 U.S.C. § 103.

3. **Obviousness**

The parties agreed that a person of ordinary skill in the art would be an instrument designer with a college degree in physics or engineering and some practical experience in the design of optical instruments. Each party proffered expert testimony on the factual question of the scope and content of the prior art. It is notable that Bio-Rad's expert, Gebbie, was the only expert capable of testifying on the basis of first-hand experience with the level of skill in the relevant time period. One of Nicolet's experts, Lowenstein, whose article was relied on to assert invalidity, said:

> As far as the designers of commercial or industrial interferometers were concerned, I think I don't know anybody or, at least not well enough to be able to form an opinion about his level of skill.

This excerpt from the testimony is produced to illustrate the importance of the jury's role in ascertaining the content of the

prior art. The jurors must discern how a person of ordinary skill in the art would have interpreted available art at the time the invention was made. The factfinder's interpretation of prior art references is necessarily guided by the credibility given the testimony of the experts. Here, the jury presumably credited the testimony of Gebbie rather than the testimony of Lowenstein in deciding what the Lowenstein article would have meant to one of ordinary skill in the art. Given the different familiarity of the experts with those skilled in the art at the relevant time, that evaluation by the jury was reasonable and cannot be successfully challenged on appeal. The only question for this court, therefore, is whether, on the facts testified to by Gebbie and presented by Bio-Rad, reasonable jurors could conclude that the invention would have been obvious to one of ordinary skill in the art at the time it was made.

Nicolet argues the claimed invention would have been obvious in view of the Lowenstein publication. The Lowenstein publication used a lamellar grating interferometer to measure refractive properties of sapphire. The interferometer used by Lowenstein had a set of stationery plates and a set of moveable plates. To analyze the sample being studied, the moveable plates were run in one direction by a motor until the motor was shut off. One run, or scan, typically took 6 to 8 hours. After one scan was completed a motor drove the interferometer back to begin a new scan. The claimed invention requires cyclical mirror movement. Lowenstein did not disclose or suggest the mirror oscillation required by the claimed invention.

Dr. Gebbie testificd that those of *ordinary* skill in the art were skeptical of Michelson rapid scan interferometers, which provide cyclical mirror movement, and would not have interpreted the Lowenstein article to suggest using a Michelson interferometer as required by the claimed invention. It appears from Gebbie's testimony that a person of ordinary skill in the relevant art would not have arrived at the claimed invention

after reading the Lowenstein article. Nicolet has not shown that reasonable jurors could not agree with Gebbie that one of ordinary skill in the art would not have derived the claimed invention after reading the Lowenstein publication.

Further, there was evidence that the claimed invention enjoyed commercial success in the measurement of electrically conductive film and epitaxial layers of semiconductors. The claimed invention permitted simple accurate measurement of substrates moving at high speeds. It reduced labor costs and increased productivity. The savings were in some instances so great that one witness said the $65,000 instrument had paid for itself in about two weeks. The jury had to consider this success in reaching its presumed conclusion that the claimed invention would not have been obvious.

We have no doubt that conflicting evidence was presented at trial by Nicolet on the appropriate interpretation of the Lowenstein publication and commercial success. That, however, does not carry Nicolet's burden on appeal.

B. Fraud

Nicolet argues the '515 patent is invalid because Flournoy, the named inventor, did not actually invent the claimed subject matter. Nicolet contends that Myron Block, not Flournoy, was the inventor. According to Nicolet, Myron Block permitted Flournoy, a DuPont engineer, to claim inventorship to induce DuPont to invest in Block Associates (a predecessor of Block Engineering founded by Myron Block). There is conflicting testimony in the record with regard to how the invention was developed. Nicolet's case on fraud principally hinges on the credibility of Myron Block. However, the development of the claimed invention described by Bio-Rad during the trial adequately supports the finding that Flourney invented the claimed subject matter.

Dr. Philip Flournoy joined DuPont in 1960 as a research

engineer in the Engineering Physics Laboratory at the DuPont Experimental Station. A group of scientists at DuPont, including Dr. Flournoy, were engaged in developing instruments for monitoring and controlling a wide variety of industrial manufacturing processes. Dr. Flournoy wanted to develop an instrument that could provide rapid information on the thickness of expitaxial layers on semiconductors of electrically conductive film, known as Mylar, during the production process. Previous techniques were undesirably slow because the spectrometers used required a relatively long period of time to produce one spectrum. Flournoy hoped that a rapid scan interferometer could provide desired spectral information rapidly in a short period of time.

In the course of investigations on measuring Mylar film and epitaxial layers, Dr. Flournoy observed the presence of small peaks ("side bursts") on either side of the main peak of an interferogram. To determine whether these small peaks were associated with the equipment or with the sample, Dr. Flournoy took interferograms of samples having different thicknesses and observed that the spacing between these peaks varied directly with the thickness of the sample. This determination led him to conclude that, with an adequate interferometer, he could construct an instrument for measuring film thickness, utilizing a rapid scan interferometer.

In March, 1961, Flournoy and his supervisor visited Block Associates to evaluate Block Associates as a vendor of rapid scan interferometers for DuPont's process control equipment needs. That trip satisfied Flournoy that Block Associates could produce sufficiently high quality equipment to satisfy DuPont's requirements.

By December 1961, Flournoy had obtained a suitable interferometer. With that instrument, he performed a series of experiments whereby he took interferograms from samples of

Mylar, detected distinguishable side bursts in the interferogram, and utilized the distance between those side bursts to calculate the thickness of the Mylar samples. The accuracy of these experimentally obtained thickness readings was verified by comparing them to the actual thickness of the film, measured with a micrometer. By July 1962, Flournoy further refined the specifications for the various operational parameters for a thickness measuring instrument.

In July 1962, there were discussions between DuPont and Block Associates concerning the possibility of Block's manufacturing the thickness measuring instrument for DuPont. In the course of these discussions, the parties recognized that Block Associates and DuPont had possibly conflicting claims to inventorship of the process and apparatus embodied in the thickness gauge. It was agreed that the parties would collect and exchange documentation of their inventions. On the basis of the exchanged documentation, the patent attorneys would determine which party was entitled to any of the invention(s) that might reside in the thickness gauge under development.

After the documents were exchanged, Block Associate's patent attorney and DuPont's patent attorney determined that Flournoy was the inventor. Specifically, they found that Flournoy could prove he had conceived the invention of measuring film thickness with reference to the side burst on the interferogram at least as early as March 23, 1961 and that he could prove a reduction to practice of that invention in December 1961. Block, on the other hand, could not prove that he or his employees had conceived the invention any earlier than May 4, 1961, nor could Block prove a reduction to practice of the invention any earlier than June 29, 1962. A memorandum was produced, and signed by both attorneys, wherein Myron Block recognized Flournoy as the inventor of the subject matter ultimately claimed in the '515 patent.

These facts adequately support the jury's presumed finding that Dr. Flournoy invented the claimed subject matter. Whether a different conclusion could have been reached on the basis of conflicting testimony presented by Nicolet at trial is not the issue before this court.

C. Compliance With The Requirements of 35 U.S.C. § 112

Nicolet argues that the '515 patent is invalid for failure to disclose the best mode and because the disclosed invention is inoperative. Both arguments are premised on the omission of Automatic Gain Control circuitry (AGC) from the specification. On appeal, Bio-Rad identifies specific testimony establishing that the disclosed invention is fully operative and that at the time the patent application was filed, the AGC was not considered a necessary part of the invention or of the best mode for practicing the claimed invention. Nicolet's arguments on these issues amount to little more than bald assertions by counsel. As appellant, Nicolet has not satisfied this court that reasonable jurors could not find that the best mode requirement was satisfied or that the claimed invention was operative.

Nicolet also asserts that the claims are vague and indefinite. Here again the argument amounts to little more than a statement by counsel supported by some evidence in the record that the language "scanning the specimen" does not have a definite, understandable meaning. Bio-Rad presented testimony showing that a person of ordinary skill in the art would understand the phrase "scanning said specimen" to mean that a movable mirror of the interferometer must reciprocate when the phrase is read in light of the specification. Nicolet has not presented a basis for overturning the jury's presumed resolution of this issue in Bio-Rad's favor.

D. Infringement

Nicolet contends its MX-ECO machines do not infringe any claims of the '515 patent for two reasons. According to Nicolet,

the method claims require light to be directed from a source onto a sample, then reflected from the sample to an interferometer and then onto a detector. Both parties agree that the MX-ECO does not follow this sequence. During operation of the MX-ECO, light moves from a source into an interferometer, then onto the sample, and from the sample to a detector. The issue here is whether reasonable jurors, after reviewing all the evidence, could have interpreted the claims to include the sequence of events followed by the MX-ECO. *Envirotech Corp.* v. *Al George, Inc.*, 730 F.2d 753, 758. 221 USPQ 473, 477 (Fed. Cir. 1984). The contested language of claim 1 is reproduced below:

> 1. A method for determining a physical property of a specimen on the basis of interferometric optical phase discrimination comprising,
>
> in sequence,
>
> directing analytical radiation upon said specimen,
>
> along a course such that there is developed an optical phase difference between radiation emanating from a first radiation-reflective surface of said specimen, second radiation reflective surface of said specimen cyclically varying at a predetermined time rate the length of the path of travel of said radiation emanating from a given one of the pair consisting of said radiation-reflective surface of said specimen, and said second radiation-reflective surface of said specimen with respect to the length of the path of travel of the radiation emanating from the other of said pair,***.

At trial, Bio-Rad presented testimony of Mr. Johnston, a patent attorney, on the subject of claim interpretation. The witness testified that to clearly require performance of one step after another in the order listed, he would add the words "and thereafter" or similar language between the listed steps. Certainly such language in claim 1 would remove any ambiguity. Because the claim could have been more clearly written to require a specific sequence, but was not, there is room for reasonable

people to interpret the claim as urged by Bio-Rad. We emphasize that our task is not to interpret the claims as though no trial had occurred. Both parties submitted testimony in support of their interpretation before the jury. Bio-Rad's interpretation prevailed and was not overturned by the trial judge. On appeal, we consider only whether reasonable jurors could have interpreted the claim in the manner presumed. *Envirotech Corp. v. Al George, Inc.*, 730 F.2d at 758, 221 USPQ at 477. We conclude that reasonable jurors could conclude the claims simply require light to travel from a source to a detector in a manner that develops an optical phase difference.

Nicolet's second theory for overturning the judgment of infringement is that the '515 patent requires determining a sample's thickness by measuring time directly from an interferogram. In contrast, the MX-ECO measures thickness of a sample by measuring the distance traveled by the reciprocating mirror between occurrences of constructive interference.

The jury presumably concluded that one of ordinary skill in the art would understand that the MX-ECO's mirror time of travel is functionally equivalent to the mirror distance traveled. The patent specification uses "time" to encompass alternative approaches for determining the distance traveled by the mirror between the occurrence of a sideburst and a reference point. When the patent claims speak of "measuring the elapsed time" they also refer to the measurement of the distance the mirror traveled from a reference point to the position where a sideburst occurs. For instance, Figure 3 of the '515 patent shows both distance of mirror travel as well as time. Both distance and time may be used to determine the distance traveled by the mirror. The jury could also reasonably have drawn the presumed conclusion from other evidence produced by Bio-Rad such as Nicolet's sales brochure which described a Michelson interferometer used in the MX-ECO and stated that the mirror velocity must be constant during the scan. The evidence pro-

duced by Bio-Rad shows that although time and distance are different, they are related in this technological setting. Because of the close relationship between time and distance in this case, we cannot conclude that the jury's finding of infringement must be reversed.

Nicolet's argument that the MX-ECO applies mathematical formulas known as fourier transforms to the data of an interferogram does avoid infringement. Steps or features added to a claimed invention do not necessarily avoid infringement. *Radio Steel Mfg. Co.* v. *MTD Products, Inc.*, 731 F.2d 840, 221 USPQ 657 (Fed. Cir. 1984).

II. Grounds For New Trial

A. Form of Verdict

Nicolet argues that a new trial is required because the form of verdict used in this case was improper. Nicolet contends that the general verdict form permitted the jury to decide questions of law. This court has already held that there is no error inherent in submitting questions of law to a jury so long as the jury is adequately instructed. *Railroad Dynamics, Inc.* v. *A. Stucki Co.*, 727, F.2d at 1514-15, 220 USPQ at 937-38. Nicolet's argument for a new trial therefore has no merit absent some harmful error in the instructions.

The instructions in this case were jointly submitted by the parties to the court. When the instructions were given to the jury, Nicolet raised no objection to any of them. Ordinarily, a party must object to an instruction in time to give the trial judge an opportunity to correct the alleged error before the jury returns its verdict. If no objection is raised, the instructions cannot be challenged on appeal unless great injustice would result. *See American Hoist & Derrick Co.* v. *Sowa & Sons, Inc.*, 725 F.2d 1350, 1364, 220 USPQ 763, 774 (Fed. Cir. 1984).

B. Instruction On Burden Of Proof

Nicolet also argues that the trial judge failed to properly instruct the jury on Nicolet's burden for proving invalidity. The jury was instructed that the patent must be presumed valid and that the burden of proving invalidity rests upon Nicolet. The trial judge also told the jury that "[t]he presumption of validity is rebuttable only by clear and convincing evidence." Nicolet contends that the jury should have been told that the presumption of validity may be weakened or destroyed when prior art more pretinent than that considered by the examiner is presented at trial. Because prior art presented at trial was more pertinent than art before the examiner, Nicolet says the jury should have been instructed that Nicolet only had to carry its burden of proof by a preponderance of the evidence.

Nicolet cannot possibly show that great injustice was caused by the challenged instruction since this court has repeatedly held that the party asserting invalidity must prove facts capable of overcoming the presumption by clear and convincing evidence. The introduction of prior art not considered by the PTO does not change the burden of proof or the requirement that evidence establish the presumption-defeating facts clearly and convincingly. *Connell* v. *Sears, Roebuck & Co.*, 772 F.2d at 1549, 220 USPQ at 199. Nicolet's challenge to the burden of proof instruction is therefore without merit.

C. Abuse Of Discovery

Here, Nicolet says that Bio-Rad abused the discovery process to such an extent that a new trial is required. The argument is not premised on failure to disclose documents but on the production of certain documents during the trial. The documents involved opinions from attorneys on validity questions.

Questions regarding abuse of the discovery process are within the trial judge's province and denial of a motion for new trial based on such abuse will be overturned only if the denial

of a new trial is shown to be an abuse of discretion. *Edgar* v. *Finley*, 312 F.2d 533 (8th Cir. 1963). The disputed evidence was discovered during trial and the documents were entered as evidence in the case. The record indicates Nicolet had an adequate opportunity to examine witnesses necessary to explain the significance of these documents and to present arguments regarding their importance on the validity issues. Under these circumstances, we cannot say that an abuse of discretion occurred when Nicolet's request for new trial was denied.

D. **Damages**

Finally, to obtain a new trial, Nicolet argues the damages award is excessive. In attacking the jury award of $3,078,000, Nicolet assumes that lost profits were awarded on 91 MX-ECO instruments sold by Nicolet and that a reasonable royalty of $18,000 per instrument was assessed on each sale of 19 other MX-ECO instruments. Bio-Rad does not challenge this presumed analysis of the jury's award, as it appears to follow Bio-Rad's arguments to the jury on the damages issue. Although we are not required to follow the analysis presumed by the parties, we do so in this case and affirm the jury award.

To obtain lost profits, a patent owner must prove that he would have made the sales but for the infringing activity. The patent owner need not prove causation as a certainty, evidence showing a reasonable probability that Bio-Rad would have made the infringing sales Nicolet made will suffice. *Gyromat Corp.* v. *Champion Spark Plug Co.*, No. 83-1081/1149, slip op. at 9 (Fed. Cir. May 22, 1984); *Lam, Inc.* v. *Johns-Manville Corp.*, 718 F.2d 1056, 1065, 219 USPQ 670, 675 (Fed. Cir. 1983). The jury was instructed that Bio-Rad is entitled to lost profits on sales Bio-Rad would have made but for Nicolet's infringement and that several factors should be considered, including:

> whether plaintiff had the existing or at least potential manufacturing and marketing capabilities to obtain

> the infringing sales, whether plaintiff's FTG-12C and defendant's MX-ECO compete with one another, whether plaintiff's and defendant's marketing efforts were aimed at the same geographical markets and categories of customers, and whether there were any particularly close substitutes for the FTG-12C and the MX-ECO.

The instruction on lost profits is not challenged on appeal. We conclude that sufficient evidence was proffered by Bio-Rad to establish a reasonable probability that in the absence of Nicolet's infringement, Bio-Rad would have sold an additional 91 thickness measuring instruments. For instance, Bio-Rad showed demand for the claimed invention by proving Nicolet's sales of infringing instruments and licenses for the production and use of instruments embodying the claimed invention by two other corporations. Bio-Rad is the only company licensed to sell instruments embodying the invention of the '515 patent, with one inconsequential exception. Texas Instruments was licensed to sell five instruments embodying the claimed invention after Texas Instruments had used them for one year. This fact alone does not preclude the award of lost profits by the jury. In addition, Bio-Rad's witnesses testified that Bio-Rad's facilities were adequate or could have been made adequate to meet the additional demand for the claimed invention.

Nicolet argues that Bio-Rad is not entitled to lost profits because Bio-Rad did not establish the absence of acceptable noninfringing substitutes, one of the factors required by *Panduit Corp.* v. *Stahlin Bros. Fibre Works, Inc.*, 575 F.2d 1152, 1156 (6th Cir. 1978), to justify an award of lost profits.*/ We con-

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*/ Although this court has accepted the *Panduit* standard as a permissible way to establish entitlement to lost profits, we have not made that standard the exclusive one for determining entitlement to lost profits. *Central Soya Co.* v. *Geo. A. Hormel & Co.*, 723 F.2d 1573, 1579, n. 5, 22 USPQ 490 (Fed. Cir. 1983); *Gyromat Corp.* v. *Champion Spark Plug Co.*, No. 83-1081, slip op. at 5 (Fed. Cir. May 22, 1984).

clude there is sufficient evidence of record for a reasonable jury to find the absence of acceptable substitutes. Bio-Rad's market survey expert testified that in surveying purchasers of the Nicolet device, 70-90% of the interviewees would have purchased Bio-Rad's FTG-12 devices had Nicolet not been present in the market. Bio-Rad also points to admissions by Nicolet that Bio-Rad was Nicolet's sole competitor. We are also satisfied that the jury could reasonably conclude from the evidence that there were no other devices which could be deemed acceptable substitutes, especially in view of the fact that Nicolet did not offer any evidence to the contrary. Indeed, it is Nicolet's burden on appeal to show that reasonable jurors could not have concluded that but for Nicolet's infringement, Bio-Rad would have sold 91 additional instruments. Nicolet has failed to carry that burden here.

Nicolet also contends that the amount of lost profits awarded is so large that the jury verdict must be overturned or a new trial ordered. The amount of lost profits awarded cannot be speculative but the amount need not be proven with unerring precision. See *Lam, Inc.* v. *Johns-Manville Corp.*, 718 F.2d at 1065, 219 USPQ at 675; *Livesay Window* v. *Livesay Industries, Inc.*, 251 F.2d 469, 472, 116 USPQ 167, 169 (5th Cir. 1958).

To support its contention, Nicolet describes the testimony of Bio-Rad's accounting expert as speculative and without any reasonable basis. Bio-Rad's expert relied on an incremental cost accounting method that resulted in a profit of about $39,650 for each domestic sales and $34,313 for each foreign sale. This calculation included all of Bio-Rad's costs, except for direct selling expenses, labor and materials. We cannot conclude that the size of the award for lost profits was too speculative simply because the jury was guided by an incremental cost accounting method.

Nicolet also argues that the reasonable royalty, presumed

to be part of the damages award, is too high. They point out that the industry royalty rate runs from three to ten percent of sales while the royalty awarded by the jury approaches one third of the selling price of the MX-ECO. Though established royalty rates are normally applicable, *Hanson* v. *Alpine Valley Ski Area, Inc.*, 718 F.2d 1075, 1078, 219 USPQ 679, 682 (Fed. Cir. 1983), they do not necessarily establish a ceiling for the royalty that may be assessed after an infringement trial. *Cf. Tektronix, Inc.* v. *United States*, 552 F.2d 343 at 347 n.5, 193 USPQ 385 at 390 n.5 (Ct. Cl. 1977), *cert. den.*, 439 U.S. 1048 (1978). Appellant has not met its burden of showing that use of a higher rate was inappropriate under the circumstances of this case.

E. **Antitrust Counterclaim**

Finally, Nicolet argues it is entitled to a new trial on its antitrust counterclaims because the jury's incorrect analysis of validity and infringement necessarily resulted in their rejection of Nicolet's antitrust claims. In veiw of our affirmance of the decisions on validity and infringement, Nicolet's argument is without merit.

III. Patent Misuse

Nicolet's answer to Bio-Rad's complaint alleged patent misuse because of bad faith threats of patent infringement suits. Nicolet's answer said: "Plaintiff is estopped from enforcing said patent No. 3,319,515 by reason of misuse thereof in the form of bad faith threats of patent infringement suits based thereon." This was the only misuse theory presented to the jury. After the jury verdict was returned, Nicolet argued two different misuse theories to the trial judge in a motion to deny enforcement of the '515 patent. The trial judge denied the motion without comment. On appeal, Nicolet relies on the same two misuse theories that were presented only to the trial judge after the jury rendered its verdict. Nicolet would have this court declare the patent in suit unenforceable.

First, Nicolet argues that Bio-Rad misused its patent in 1969-1970 when Digilab refused to sell unpatented interferometers to Texas Instruments unless Texas Instruments took a license under the '515 patent. Second, Nicolet contends that misuse occurred when Bio-Rad and DuPont agreed to jointly enforce the '515 patent against Nicolet and created a joint litigation fund for that purpose. We do not address the merits of these contentions because Nicolet has waived the right to raise these misuse issues.

Misuse is an affirmative defense that must be pleaded and proved. 35 USC §282 (1976); *Trio Process Corp.* v. *L. Goldstein's Sons, Inc.*, 461 F.2d 66, 74, 174, USPQ 129, 135 (3d Cir. 1972), *cert. denied*, 409 U.S. 997 (1972). Nicolet and Bio-Rad both asked for a jury trial on all the issues. No issues were reserved for trial to the court only. In fact, in its Joint Pretrial Statement, Nicolet said "Bifurcation or separate trials of any issues is neither desired nor feasible." Because the affirmative defenses argued on appeal were not pleaded in Nicolet's answer or presented to the jury, we hold these defenses were waived and we need not consider them further. *See id.* at 461 F.2d at 74, 174 USPQ at 135.

Nicolet relies on *In re Yarn Processing Patent Validity Litigation*, 472 F.Supp. 170, 205 USPQ 758 (S.D. Fla. 1979) (*Yarn Processing*) for the proposition that misuse *must* be decided by the court and not the jury. Nicolet's reliance on this case is unfounded. The plaintiff in *Yarn Processing* sued for infringement occurring after misuse had been purged and demanded a jury trial. The District Court granted a motion for separate trial to the court of the purged issues because they were separable from the infringement issues and their separate adjudication would expedite the litigation. The court concluded that trying the equitable misuse defense before a judge did not violate plaintiff's right to a jury trial. The decision in *Yarn*

Processing, therefore, has no bearing on this case where all issues were to be tried to the jury.

IV. Prejudgment Interest

The trial court denied Bio-Rad's request for prejudgment interest before the United States Supreme Court decision in *Devex Corp.* v. *General Motors Corp.*, 51 U.S.L.W. 4613 (May 24, 1983) was available. In that case, the Supreme Court said that prejudgment interest is compensatory, not punitive, and should be awarded under 35 U.S.C. § 284 absent some justification for withholding such award. Here the district court denied prejudgment interest but did not indicate that there was any reason for denying prejudgment interest. The determination of whether such a reason is present is for the trial court to ascertain in the first instance. We therefore *vacate* the trial court's denial of prejudgment interest and *remand* for an award of prejudgment interest or a determination that some specific justification exists for denying prejudgment interest. In all other respects, the judgment is *affirmed*.

AFFIRMED-IN-PART, VACATED-IN-PART, AND REMANDED

UNITED STATES COURT OF APPEALS
FOR THE FEDERAL COURT

July 24, 1984

ERRATUM

Appeal Nos. 83-829/83-864

BIO-RAD LABORATORIES, INC., a Delaware Corporation v. NICOLET INSTRUMENT CORPORATION, a Wisconsin Corporation.

Decided: July 12, 1984

Please make the following correction:

Page 24, ultimate line – change "does avoid"
to –does not avoid–

UNITED STATES COURT OF APPEALS
FOR THE FEDERAL COURT

BIO-RAD LABORATORIES, INC., a Delaware Corporation, *Appellee,*	)	
v.	)	No. 83-829 83-864
NICOLET INSTRUMENT CORP., a Wisconsin Corporation, *Appellant.*	)	

ORDER

A petition for rehearing and a suggestion for rehearing in banc having been filed in this case,

UPON CONSIDERATION THEREOF, it is Ordered by the court that the petition for rehearing be, and the same is hereby, Denied.

The suggestion for rehearing in banc is declined.

FOR THE COURT

/s/ George E. Hutchinson
George E. Hutchinson, Clerk

August 10, 1984
Date

cc: Harold C. Hohbach
Roger L. Cook